Biodiversity Outcomes Resulting from Ecological Management in Pūtaringamotu/Riccarton Bush

A thesis submitted in partial fulfilment of the Master of Science majoring in Environmental Science

MSc (Environmental Science)

Georgia Sharp

New Zealand School of Forestry

University of Canterbury

Christchurch

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Abstract

Pūtaringamotu/Riccarton Bush is a 7.8-hectare remnant of kahikatea (*Dacrycarpus dacrydioides*) forest found in the urban centre of Christchurch. The remnant forest was originally mismanaged using an English woodlot approach, this was rectified when an ecological management regime was implemented in the 1970s. This has allowed the indigenous flora and fauna to recover following the initial mismanagement period. The objective of this research was to determine whether fundamental changes have occurred in Pūtaringamotu because of the establishment of proactive management. This was assessed by quantifying the changes in two biodiversity groups; vegetation and avifauna over the last 20 years and 15 years respectively to evaluate whether effective management of the forest has resulted in a significant improvement in biodiversity.

The vegetation of Pūtaringamotu was investigated by measuring ten permanent sample plots to assess changes in abundance, composition and diversity using proxies of cover, basal area, and species richness and Shannon's index respectively. It was found that no significant differences between years occurred over the 20-year period. This indicates that fundamental differences in vegetation are yet to occur in Pūtaringamotu. However, insignificant differences in abundance and composition are present with more plots having increases than decreases for cover and basal area. In juxtaposition, diversity experienced more stabilisation or decreases than increases for species richness and diversity over the 20-year period. This suggests marginal changes are still occurring in Pūtaringamotu. Overall, vegetation in Pūtaringamotu has been maintained as a result of the establishment of proactive management in the remnant.

The avifauna of Pūtaringamotu was assessed using five-minute bird counts to see if changes have occurred in abundance, composition, and diversity measured through proxies of total species, indigenous and exotic bird presence, and species richness and Shannon's index respectively. It was found that no significant differences occurred between years, indicating fundamental changes in avifauna are yet to occur in Pūtaringamotu. Exotic avifauna remain more dominant in Pūtaringamotu than indigenous avifauna with significant differences occurring between the two groups for species richness (ANOVA, $F = 36.57$, $df = 1$, $P = 0.03$) and Shannon's index (ANOVA, $F = 32.42$, $df = 1$, $P = 0.03$), This suggests that management thus far has not resulted in more heterogeneous avifauna. Overall, the avifauna of Pūtaringamotu have been maintained in the remnant as a result of the establishment of proactive management.

It is likely that proactive ecological management in Pūtaringamotu over the last 50 years has had positive effects on maintaining biodiversity values in the remnant. This information will be useful for informing future management protocols utilised for Pūtaringamotu. It is recommended the Riccarton Bush Board of Trustees continue to employ current management interventions as they are effectively maintaining vegetative and avifaunal biodiversity. It is also recommended that further management efforts should focus on addressing the incursion of weeds along the remnant edge by increasing weed control, culling Rock Pigeon which act as a pest within the urban remnant, and facilitating biological recruitment into the forest by artificially introducing new species to the remnant as the isolative nature of the remnant restricts significant sources of biological recruitment.

Key words: ***Riccarton Bush, Pūtaringamotu, forest remnant, ecosanctuary, biodiversity, ecological restoration, vegetation, avifauna***

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1 Introduction

1.1 Overview of Research

Pūtaringamotu/Riccarton Bush hereafter referred to as Pūtaringamotu is a remnant patch of kahikatea (*Dacrycarpus dacrydioides*) forest located in urban Christchurch. The remnant has been ecologically managed since the 1970s for the goal of protecting and enhancing indigenous flora and fauna including mahinga kai and taonga species. The remnant as it exists today has been formed from the management history of the forest. Prior to the introduction of ecologically based management protocols the remnant went through a long period of benign neglect where it was managed akin to an English woodlot rather than a highly significant indigenous forest remnant. The ecologically based management of Pūtaringamotu has thus far involved cessation of mowing and raking, removal and replacement of exotic vegetation, weed control, irrigation, reduction and formalisation of walking tracks, and the establishment of a pest proof fence (Riccarton Bush Trust, 2015). This research aims to provide an understanding of how vegetation and avifauna biodiversity have changed over time in the remnant to determine if changes have occurred in Pūtaringamotu as a result of the introduction of proactive ecologically based management.

1.2 New Zealand Ecology

1.2.1 Historical Context

New Zealand has been isolated from other landmasses for approximately 80 million years (Campbell-Hunt, 2008), allowing flora and fauna to evolve in isolation leading to high levels of unique endemic species being present (Burns, Innes, & Day, 2012; Dymond, Ausseil, Peltzer, & Herzig, 2014; Department of Conservation, 2020). New Zealand's biodiversity is unusual, in that, few terrestrial mammalian species were present in New Zealand prior to the arrival of humans (McGlone, 1989). This has caused the vegetation and avifauna of New Zealand to have unique evolutionary traits as species evolved to fill niches commonly occupied by mammals and developed defensive strategies against reptilian and avifaunal herbivory and predation (Russell, Innes, Brown, & Byrom, 2015). The prominence of unique morphological and behavioural traits is most noticeable in New Zealand's endemic avifauna which evolved to be flightless, have large body mass, and ground nest likely due to the absence of mammalian predation (Duncan & Blackburn, 2004).

In comparison to other countries New Zealand has undergone late anthropogenic development, with Polynesian travellers first arriving in New Zealand approximately 800 years before present and European settlers arriving from the 1800s (McGlone, 1989; McWethy, Whitlock, Wilmshurst, McGlone, & Li, 2009). Prior to the arrival of humans, the predominant vegetation type was indigenous forest which covered between 80% - 85% of the total terrestrial land area (Smith, Cochrane, Stephenson, & Gibbs, 1997; Ministry for the Environment, 2018). Since the arrival of humans, the area of indigenous forest has been significantly reduced. Pre-European effects were largely restricted to accidental burnings (McGlone, 1983; Perry, Wilmshurst, McGlone, McWethy, & Whitlock, 2012) whereas

European arrival resulted in an acceleration of indigenous forest removal via felling of trees for timber and introduction of exotic vegetation causing habitat loss (Ewers, et al., 2006; Campbell-Hunt, 2008). Another significant effect on New Zealand's indigenous biodiversity was the accidental and deliberate introduction of several mammalian species (McGlone, 1989; Parkes & Murphy, 2003). This had devastating effects on New Zealand's biodiversity due to the browsing and predation on vulnerable endemic species which had ill-equipped evolutionary traits to cope with the new threat (Blackburn, Cassey, Duncan, Evans, & Gaston, 2004; Campbell-Hunt, 2008).

1.2.2 Present Day

Today, only 23% of New Zealand's original indigenous forest cover remains (Ministry for the Environment, 2018) which in many parts of New Zealand is restricted to remnant patches. Protecting these remaining remnant patches scattered across lowland New Zealand is of utmost importance as the old growth indigenous forest provides high biodiversity value having been constantly present on sites prior to anthropogenic change (Norton, Butt, & Bergin, 2018). Remnant survival continues to be threatened by encroaching agriculture and urbanisation. This is because increased land use change and increased pest presence leads to a decrease in indigenous biodiversity as remnant patches are fragmented and isolated in space (Campbell-Hunt, 2008; Olejniczak, Spiering, Potts, & Warren, 2018). Maintaining remnants in the landscape will allow New Zealand's indigenous flora and fauna to continue to thrive in high quality and niche habitats which would have once been abundant across New Zealand.

While the indigenous forest found in New Zealand today is not the same as that found before human arrival due to past and present disturbance, it is still vital that systems are put in place to protect remnant patches to ensure the continued presence of New Zealand's indigenous flora and fauna for future generations (Wyse, Wilmshurst, Burns, & Perry, 2018). Much of the remaining indigenous forest cover found in New Zealand is protected on both public and private land through the Department of Conservation and the Queen Elizabeth II National Trust respectively, although significant areas remain unprotected (Pannell, Buckley, Case, & Norton, 2021). In New Zealand most indigenous forest cover is contained on conservation land (Dymond, et al., 2014; Clarkson & Kirby, 2016) which accounts for 32% of public land area (Campbell-Hunt, 2008). Despite this, land protected for conservation purposes does exhibit a bias towards inland and upland regions leaving a proportion of indigenous forest unprotected (Norton, Butt, & Bergin, 2018). To counteract this indigenous forest found on private land holdings can be protected in perpetuity when private landowners voluntarily enter a covenant with the Queen Elizabeth II National Trust (Saunders, 1996; Norton, et al., 2018), due to the voluntary nature of this scheme large areas of remnant patches remain unprotected. It is important to note, that the act of formally protecting a site does not equate ecological sustainablity (Norton, 1988), in reality, to sustain a site ecologically based management protocols must be put into place and this issue forms the focus of this research.

1.3 Urban Ecology

Remnants in urban locations make up 8.9% of the New Zealand urban matrix (Clarkson, Wehi, & Brabyn, 2007). It is important that remnants continue to be sustained within urban environments as biodiversity continues to be impacted by the expansion of the urban matrix. The major threat to the continued sustainability of old growth forest remnants located in urban areas is fragmentation which causes loss of connectivity, hence decreasing the presence of New Zealand indigenous species in urban environments (McKinney, 2002; Olejniczak, et al., 2018). Whilst most urban remnants face this issue Pūtaringamotu presents a unique situation as it has been isolated in space for over 100 years reducing the prominence of this threat, instead Pūtaringamotu is threatened by invasion of unwanted species, anthropogenic influences, and changes to ecological processes. Succession processes in urban remnants are complicated by anthropogenic influences including increased pest presence, incursion of unwanted vegetation, pollution, and low water tables. For this reason, management should consider the specific drivers of change within a remnant resulting in different management approaches being utilised for the unique situation of individual remnants (Dwyer, Nowak, & Noble, 2003).

Management can range from low intervention where there is little input into the ecosystem to high intervention where the ecosystem is extensively managed to allow for manipulation depending on the specific goals for the urban remnant. Pūtaringamotu is currently held in a static state as the natural succession process requires flooding of the remnant which can no longer occur due to the surrounding built urban matrix. Hence, the management of Pūtaringamotu focuses on maintaining the remnant as a static entity of *D. dacrydioides* forest by using extensive ecologically based management protocols to allow the remnants indigenous flora and fauna to be enhanced and protected (Riccarton Bush Trust, 2015).

1.3.1 Urban Restoration Goals

Ecological restoration is the process of assisting the physical and functional recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration International Science & Policy Working Group, 2004). The purpose of restoration should be to speed up succession so to achieve a desired outcome in a shorter period. When restoring remnants, a continuum from restoring aesthetic value to restoring a fully functional and self-sustaining ecosystem containing predominately indigenous species exists. Therefore, desired outcomes should be formulated prior to the beginning of restorative work to allow measurement of whether goals for restoration have been met based on predetermined objectives. Success can be measured in several ways, with the typical approach of measurement in New Zealand being long-term biodiversity monitoring. Biodiversity monitoring involves taking inventory of ecological data at regular intervals to gain an understanding of how a remnant has changed over time. This gives insight on how remnant forests are changing in response to urban intrusion and restorative management (Choi, 2004; Pech & Maitland, 2016; Wallace & Clarkson, 2019).

The restoration goal for Pūtaringamotu is to establish a fully functioning ecosystem based on the historic indigenous forest of the lower Canterbury Plains, within the constraints of the present environment (Burns, et al., 2012). This goal has been selected as objectives should not remain static and bound by historical ecosystem elements but change as the ecosystem evolves (Simberloff, 1990; Choi, 2004). Specific goals from the Riccarton Bush/Pūtaringamotu management plan include protecting and enhancing flora and fauna of the indigenous forest including mahinga kai and taonga species, promoting the natural and cultural heritage values of the remnant, and increasing visitation (Riccarton Bush Trust, 2015). In Pūtaringamotu restorative measures are currently being undertaken to regenerate the small pocket of indigenous forest for the purpose of further protecting ecological biodiversity (Matapopore Charitable Trust, 2020). A reconstruction approach is being utilised where biodiversity is managed on the site to support natural regeneration. Using management protocols aligned with the goals for Pūtaringamotu has allowed the effects of urbanisation to be mitigated in the remnant by decreasing degradation effects. This research will assess the success of restorative management in Pūtaringamotu by monitoring the biodiversity of vegetation and avifauna to understand temporal trends. This will be useful for determining if current management protocols are the most effective means for protecting indigenous flora and fauna in Pūtaringamotu.

1.3.2 Remnant Ecosanctuaries

Sanctuary is defined as “protection or safe place, especially from someone or something being chased or hunted.” Hence, an ecosanctuary is an area that provides measures to protect indigenous biodiversity. They are defined as restoration projects which implement management controls for broad scale ecosystem recovery including floral and faunal components. Ecosanctuaries are a relatively recent innovation used to protect and restore mainland habitats using extensive management protocols and isolative measures. It is important to note when managing ecosanctuaries changes can be manipulated but systems cannot be reversed. Therefore, goals for ecosanctuaries should focus on returning to a natural state within the constraints of the present-day including climate change, invasions, extinctions, and past management (Molloy, 1995; Saunders & Norton, 2001; Choi, 2004; Burns, et al., 2012; Campbell-Hunt & Campbell-Hunt, 2013).

Ecosanctuaries are prevalent throughout the New Zealand landscape with Innes et al. (2019) finding there has been annual growth in establishment of ecosanctuaries since 2004, with 600+ ecosanctuaries currently established in the New Zealand landscape (Peters, Hamilton, & Eames, 2015; Innes, et al., 2019). As of 2015, ecosanctuaries accounted for just 0.2% of the New Zealand mainland area, despite this they are highly important for maintaining indigenous flora and fauna on mainland New Zealand (Russell, Innes, Brown, & Byrom, 2015). Ecosanctuaries are often established in places where they are relics of lowland ecosystems which would have once been extensive prior to anthropogenic interference and have also been established disproportionally in urban areas compared to rural areas (Toft, Ford, Sullivan, & Stewart, 2019). This has been attributed to community driven interest in protecting flora and fauna in urban environments (Burns, et al., 2012). Pūtaringamotu fits into this category as it is established in the urban centre of Christchurch.

1.3.2.1 Benefits of Nature

Remnants located in urban environments provide greenspace for the community by offering a space where people can engage with nature within city limits. Globally 48% of the human population live in urban areas (Miller, 2005) and in New Zealand 87% of the population live in urban or peri-urban areas (Department of Internal Affairs, n.d.). Therefore, remnant forests provide an opportunity for people to escape the built urban matrix. Having greenspace within the urban matrix reduces the likelihood of nature deficit disorder or extinction of experience occurring. These terms have arisen as the urban matrix has expanded, due to the lack of opportunity for people to engage with nature as it is not readily accessible (Soga & Gaston, 2016). Utilising urban remnants as greenspace plays a critical role in improving people's overall health and wellbeing (Kuo, 2013; Stanley, et al., 2015). Greenspace in the form of remnants is also fundamental for Māori living in urban areas as it allows the practice of kaitiakitanga to be maintained helping to improve sense of identity and wellbeing (Walker, Wehi, Nelson, Beggs, & Whaanga, 2019). The integration of greenspace into the urban environment can improve wellbeing by bringing people closer to nature by; reducing the time taken to reach a greenspace, making greenspaces fit the users desired experience, and encouraging visits to greenspace all of which can be achieved in urban remnants open to the community (Kuo, 2013).

1.3.2.2 Environmental Challenges for Urban Ecosanctuaries

Continued protection and management of ecosanctuaries is highly important to counteract the challenges faced in urban remnants including no sources of biological recruitment, low connectivity, novel assemblages, and lack of knowledge (Clarkson & Kirby, 2016). Ecological barriers are more prominent in urban ecosanctuaries as they are more likely to be isolated in space due to prior fragmentation and are surrounded by the built urban matrix reducing opportunities to enhance connectivity. This is an issue as low or no connectivity causes biological recruitment to slow. In the absence of connectivity species are unable to move across the landscape and are unable to colonise new sites leading to small and isolated populations (Clarkson & Kirby, 2016; Wallace & Clarkson, 2019). This negatively impacts evolutionary potential and short-term fitness of species due to loss of genetic variation, which is a concern as a reduction in genetic diversity in small populations can lead to less adaptive potential to respond to environmental changes. Reducing the chances for adaptive potential is concerning as in urban environments environmental changes occur on a more regular basis and are often exacerbated by the built urban matrix (Wallace & Clarkson, 2019).

Currently there has been little scientific research conducted on how to work within the constraints of small urban remnants, and this lack of appropriate knowledge on best practice management protocols is a disadvantage. Management knowledge is readily available for larger urban remnants, but it remains unknown whether this knowledge can directly translate to the management of small urban remnants. It has been found that the biggest biodiversity gains are achieved in the largest remnants containing established populations of generalised and specialised species. This is because larger remnants are more likely to contain a range of habitat types to support more species and edge effects are less prominent as the threats from the urban environment are unlikely to permeate to the centre of a large ecosanctuary (Bender, Contreras, & Fahrig, 1998). Despite this, smaller ecosanctuaries should not be discredited for the biodiversity gains which can be achieved. The viability of maintaining a small aging old growth forest in an urban setting remains possible if management techniques are used to control for sources of biological recruitment. This can be achieved through creation of linkage corridors or artificial introduction of appropriate indigenous species into a remnant (Clarkson & Kirby, 2016).

1.3.2.3 Ecosanctuary Management

Management within ecosanctuaries is highly important to ensure indigenous flora and fauna is actively conserved (Campbell-Hunt & Campbell-Hunt, 2013). Commonly this is achieved by a multi-level pest species removal plan created to stop predation within indigenous remnants. New Zealand urban ecosanctuaries tend to do this using a ring-fencing approach which involves establishing a pest proof fence around the entirety of an area to be protected. To be effective pest proof fences should be of suitable height, have a rounded top to prevent climbing, have a subsurface layer to prevent burrowing, have a mesh size suitable for the exclusion of all pest species, and be frequently maintained to ensure ongoing protection against pest species reinvasion. Using appropriate fencing creates an ecosystem free from the impact of pests after an eradication programme has been undertaken (Burns, et al., 2012). Biodiversity response rates are highest in ecosanctuaries where pests have been excluded. This occurs due to island ecology theory becoming applicable to mainland ecosanctuaries, wherein residual biodiversity is able to flourish on mainland ‘islands’ following removal of pests (Bellingham, et al., 2010).

Previous studies in two New Zealand ecosanctuaries; Zealandia an urban ecosanctuary in Wellington and the largest true ecosanctuary Maungatautari in Pukeatua, have indicated ecosanctuaries are able to maintain viable populations of vegetation and avifauna. In Zealandia improvements have been apparent in vegetation with increased seedling densities and changes to composition occurring as the remnant experienced re-establishment of species previously palatable to pests (Nugent, Whitford, Innes, & Prime, 2002; Blick, Bartholomew, Burrell, & Burns, 2008). Within Maungatautari vegetation has also improved, with fenced areas having higher numbers of fruiting vegetation compared to unfenced areas (Burns, et al., 2012). As well as this, five-minute bird counts in Maungatautari have shown doubling of the avifauna population since the creation of pest free zones (Innes, et al., 2012). These improvements are likely to have occurred as the exclusion of pests causes increased avifauna presence in remnants which are able to facilitate ecological processes such as pollination and seed drop. Overflow of indigenous flora and fauna into the surrounding urban matrix from remnant ecosanctuaries is likely to occur, as has been viewed in Wellington where increased presence of indigenous biodiversity has been found outside ecosanctuaries concurrent with improvements in the ecosanctuary (Clarkson & Kirby, 2016; Tanentzap & Lloyd, 2017).

1.4 Thesis Objectives

1.4.1 Problem Statement

To date a gap in knowledge exists on how key biodiversity groups respond to management protocols in established small urban forest remnants across New Zealand (Wallace & Clarkson, 2019). Studies have been conducted on larger and more prominent ecosanctuaries such as Zealandia and Maungatautari but there is little data available on small ecosanctuaries, especially in urban environments (Burns, et al., 2012; Innes, et al., 2019). The motivation for this research is to fill this knowledge gap by assessing the effectiveness of management for maintaining and enhancing biodiversity in the small 7.8 ha urban forest remnant Pūtaringamotu.

1.4.2 Relevance of Research

This research assesses the effects of proactive ecologically based management on two key biodiversity groups vegetation and avifauna. This was done by assessing abundance, composition, and diversity to measure whether Pūtaringamotu biodiversity outcomes have been maintained, improved, or diminished as a result of establishing proactive management protocols in the remnant. The research is largely an update on the summary of biodiversity provided in the book Riccarton Bush: Pūtaringamotu which reflects the condition of the forest from the 1970s to 1980s when ecologically based management was first implemented (Molloy, 1995). The monitoring of biodiversity outcomes is important because it shows whether management interventions have been successful based on established goals and helps in formulating future management plans (Norton, 2018).

Currently there is a lack of nationwide protocol for management of urban remnants and a lack of expertise present in many community groups attempting to improve biodiversity values. For many remnant restorations the primary goal is to restore ecological integrity which includes establishing indigenous dominance and species occupancy (Watts, et al., 2014; Innes, et al., 2019). The goal of management in Pūtaringamotu aligns with this, therefore this research will also be useful for providing knowledge on management to others managing urban forest remnants across New Zealand reducing the need for the current trial-and-error approach adopted by many community groups managing urban remnants (Innes, et al., 2019; Wallace & Clarkson, 2019).

1.4.3 Research Questions

The overall goal of this research is to provide an answer to the question 'have fundamental changes occurred in Pūtaringamotu as a result of proactive management?' The thesis shall answer this by meeting three main objectives:

1. To assess whether vegetation abundance, composition, and diversity has changed in the last 20 years in Pūtaringamotu,
2. To assess whether avifauna abundance, composition, and diversity has changed in the last 15 years in Pūtaringamotu, and,
3. To provide an understanding of how biodiversity in Pūtaringamotu has responded to changes in management in recent years and make recommendations for future management.

This thesis will be of use to the Riccarton Bush Board of Trustees for the purpose of providing a comprehensive understanding of how key biodiversity groups have responded to management interventions implemented within the remnant. Overall, this thesis will answer the question; *have fundamental biological changes occurred in Pūtaringamotu as a result of proactive management established in this indigenous forest remnant?*

2 Study Site: Pūtaringamotu/Riccarton Bush

2.1 Overview

Pūtaringamotu is an old growth indigenous forest remnant located in the urban centre of Christchurch and is one of the oldest protected urban forest remnants in New Zealand (Clarkson & Kirby, 2016). It is an important mahinga kai site for the Ngāi Tūāhuriri rūnanga to whom the forest is known as Pūtaringamotu - the severed ear, due to its isolation from the surrounding ecosystem resulting from anthropogenic changes on the lower Canterbury Plains (Matapopore Charitable Trust, 2020). It is the sole remnant of podocarp forest remaining on the Canterbury Plains representing 2% of the original forest cover in the region (Matapopore Charitable Trust, 2020). It is considered an ecosanctuary for New Zealand's indigenous flora and fauna having been formally protected since 1914 when it was gifted to the people of the Canterbury region by the Deans family; the European settlers of the land, and gazetted as a reserve (Molloy, 1995; Riccarton Bush Trust, 2015). This gazettal gave Pūtaringamotu formal protection allowing the site to be maintained in perpetuity under several clauses including:

- "That the property be named 'The Riccarton Bush' and be used and kept for all time for the preservation and cultivation of trees and plants indigenous to New Zealand,
- That the land be vested in and controlled by a Board of five members, two to be nominated by the Christchurch City Council, two by members of the family of John Deans II, and one by the Royal Society of New Zealand Canterbury branch,
- That the public have free entrance at such hours and subject to such restrictions and regulations made by the Board,
- That the Christchurch City Council provide an annual sum of at least $200 for or towards the maintenance and upkeep of Riccarton Bush, and,
- That the Christchurch City Council promote legislation to incorporate the Board as a body corporate with perpetual succession and a common seal (Riccarton Bush Act 1914; Riccarton Bush Amendment Act 2012)."

Arrival of Polynesian travellers from approximately 800 years before present and subsequent arrival of European settlers from the 1800s significantly reduced the area of forested land and altered the ecosystem of the Canterbury region. Pre-European effects were largely restricted to accidental burnings by Māori reducing the overall area of forest (McWethy, et al., 2009; Norton, 2020). As well as this, the introduction of the Polynesian dog and Polynesian rat led to predation in ecosystems once free of mammalian pests (McGlone, 1989). Arrival of European settlers accelerated the rate of change in the Canterbury region as forested areas were exploited for timber, several mammalian pests were introduced, and addition of exotic vegetation occurred creating a highly modified landscape (Molloy, 1995; Norton, 2020).

Prior to proactive management initiatives being implemented in Pūtaringamotu in the 1970s, the indigenous biodiversity significantly declined due to the utilisation of an English woodlot management approach. Despite being gazetted as a reserve for indigenous species preservation, management in this era involved mowing and raking of the forest floor and burning of leaf litter and woody material. This severely impacted biodiversity in the remnant forest as understory establishment could not take place as seedling germination was prevented, surface roots of *D. dacrydioides* were damaged by mowing, and decaying material was removed reducing food sources for avifauna. As a result of this, the forest present today is a highly modified version of the original forest which would have once covered the lower Canterbury Plains (Molloy, Burrows, Cox, Johnston, & Wardle, 1963; Riccarton Bush Trust, 2015).

Pūtaringamotu today encompasses a fenced area of 7.8 ha of indigenous forest holding a significant level of indigenous biodiversity. The remnant is a relic of the indigenous forest which would have once covered larger areas of the lower Canterbury Plains, with its structure and composition influenced by anthropogenic and natural means. Significant changes in Pūtaringamotu have been caused by loss of connectedness instigated by Polynesian burnings and later encroaching urbanisation leading to Pūtaringamotu becoming an ecological island isolated in the region from significant sources of biological recruitment for over 100 years (Chinn, 2006).

The remnant forest present today allows for research into an indigenous forest type largely lost from the Canterbury Plains and also provides a place for the community to enter an ecological oasis in the confines of the city (Molloy, 1995). The remnant is present in an area that would have otherwise been lost to land use change because of the forward-thinking actions taken by the Deans family to preserve the forest. It is important to study the remnant with an understanding of its anthropogenic and natural history to recognise why the forest exists in the form it does today, as well as this it is important to perceive how factors present in the current management may impact the future of the remnant. This research quantifies the present state of biodiversity in the forest to assess whether ecological management has had noticeable impacts within the remnant.

2.2 Site Selection and Description

Pūtaringamotu provides a unique opportunity to assess the effects of management over a long period due to a history of scientific studies on different areas of biodiversity dating back to the 1870s (Molloy, 1995). It has been selected as the study site for this research as there is large amounts of readily accessible data available on the key biodiversity groups vegetation and avifauna. Pūtaringamotu has also been selected as there is evidence of an established proactive management regime present over the last 50 years (Riccarton Bush Trust, 2015). The management of Pūtaringamotu is typical of that used across many New Zealand ecosanctuaries (Innes, et al., 2019) therefore the location provides a baseline for assessment of whether management has been successful for maintaining or improving biodiversity outcomes in a small urban indigenous forest remnant.

Pūtaringamotu is located in the urban centre of Christchurch between Ngahere Street and Rata Street, Riccarton (Fig. 1) at 43° 31' S, 172°, 35' E (Riccarton Bush Trust, 2015). The site exists approximately 30 m above sea level (Burle, 2020) and is underlaid by water bearing free gravels of the Springston formation (Molloy, 1995). Differential rainfall is experienced in Christchurch throughout the year averaging an annual rainfall of approximately 620 mm with drier summers and wet winters (National Institute of Water and Atmospheric Research, 2010). The temperature in Christchurch is highest in January averaging a daily temperature of 21.4 °C, dropping to an average daily temperature of 10.2 °C in July when frequent morning frosts occur (McGann, 1983).

Figure 1: Pūtaringamotu property.

Pūtaringamotu is a relic of indigenous forest that would have once been present across parts of lowland Canterbury which contained reasonable groundwater or were subject to river flooding. The forest is a remnant of first-generation floodplain kahikatea (*D. dacrydioides*) forest on the Canterbury Plains which formed after the flooding of the Waimakariri River 600 years before present allowing for establishment of *D. dacrydioides* on freshly formed surfaces (Norton, 2020). Today it remains the only place on the lower Canterbury Plains to have surviving *D. dacrydioides* forest (Molloy, 1995; Riccarton Bush Trust, 2015; Norton, 2020). Presently the forest structure contains emergent *D. dacrydioides* and *Elaeocarpus hookerianus*, a subcanopy of *Cordyline australis*, *Melicytus ramiflorus*, *Pittosporum tenuifolium*, *Pittosporum eugenioides*, *Sophora microphylla, Hoheria sexstylosa*, and *Plagianthus regius*, climbing plants including *Passiflora tetrandra*, *Parsonsia heterophylla*, *Rubus australis*, and *Muehlenbeckia australis*, and a forest floor cover of ferns and *Microlaena avenacea* (Norton, 2020). The forest is broken into five distinct structural composition units; dense kahikatea forest, broadleaved forest with scattered kahikatea, kahikatea-cabbage tree forest, dense broadleaved forest, and a cleared and replanted forest fringe (Fig. 2).

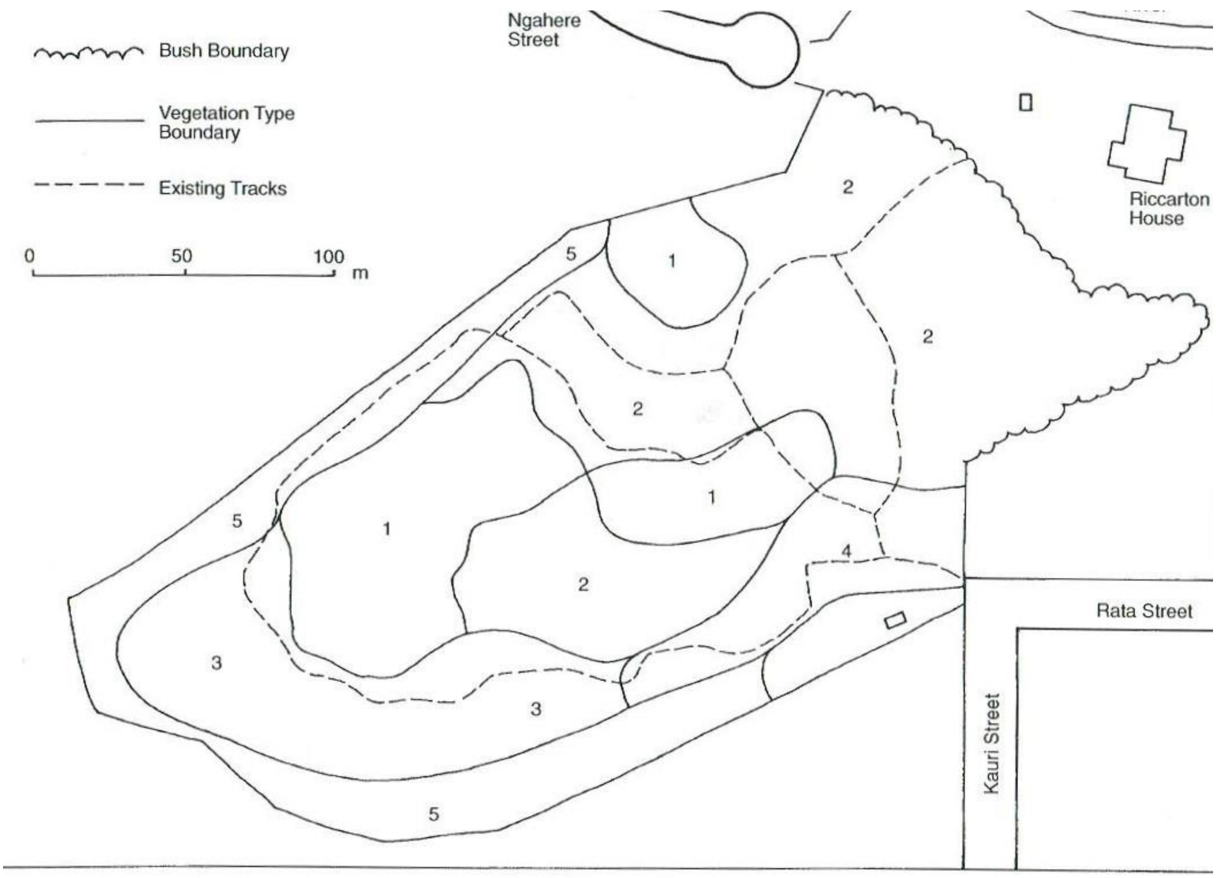

FIGURE 1: Forest vegetation of Riccarton Bush.
1. Dense kahikatea forest
2. Broadleaved forest with scattered kahikatea
3. Kahikatea—cabbage tree forest
4. Dense broadleaved forest
5. Cleared and replanted forest fringe

Figure 2: Location of vegetative structural composition units (Molloy, 1995).

2.3 Restoration Objectives

Pūtaringamotu is managed to facilitate natural processes, with the primary goal being ecological restoration of the forest to a pre-European state (Riccarton Bush Trust, 2015). Over an extended timeframe this will result in the *D. dacrydioides* forest being replaced by an angiosperm dominated canopy with scattered emergent *D. dacrydioides* as succession occurs (Norton, 2020), although current management is focused on holding the remnant in a static state as *D. dacrydioides* forest. Ecological restoration is defined as assisting the physical and functional recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration International Science & Policy Working Group, 2004). In the case of Pūtaringamotu management is used to counteract the damaging effects of the management period of benign neglect that occurred in Pūtaringamotu prior to the 1970s. The current specific management objectives for the indigenous forest set out in the Riccarton Bush/Pūtaringamotu management plan include:

- "Protect and enhance the indigenous flora and fauna of Riccarton Bush/Pūtaringamotu indigenous forest, including mahinga kai and taonga species,
- Promote the natural and cultural heritage values of the Riccarton Bush/Pūtaringamotu property, and,
- Increase visitation to Riccarton Bush/Pūtaringamotu (Riccarton Bush Trust, 2015)."

To achieve these objectives, it is necessary to examine how the forest structure and composition has changed over its lifetime, assess the current state of management in the remnant, and make recommendations for future management which will continue to restore the remnants flora and fauna improving biodiversity outcomes for Pūtaringamotu. This research will assist in achieving the objectives set out in the Riccarton Bush/Pūtaringamotu management plan by reviewing the current state of the forest via monitoring of the key biodiversity groups vegetation and avifauna to assess whether current management is effective for achieving the objectives set out in the management plan.

2.4 Management Interventions

Early management in Pūtaringamotu was akin to that of an English woodlot causing damage to the indigenous forest. The management regime throughout this period included mowing and raking of the forest floor, burning of leaf litter and woody material, and deliberate introduction of exotic vegetation. This management approach caused substantial damage to the forest by supressing understory growth and damaging emerging *D. dacrydioides* roots (Molloy, 1995; Norton, 2020). Proactive ecologically based management measures were introduced from the 1970s including cessation of mowing and raking, removal and replacement of exotic vegetation, weed control, irrigation, formalisation of the walking tracks, and establishment of a pest proof fence with subsequent pest eradication (Riccarton Bush Trust, 2015). The installation of various management interventions in Pūtaringamotu has been incremental but as a collective have resulted in large changes in the remnant forest (Molloy, 1995; Norton, 2018).

The cessation of mowing and raking from 1975 has had many positive effects including reestablishment of seedling germination, allowing for surface roots of *D. dacrydioides* damaged by mowing to heal, and decay of material in-situ. A strong understory layer has been able to establish as germination of seedlings has been able to take place in the leaf litter layer, and root rot caused by root damage has been prevented which could have resulted in potential tree mortality (Molloy, 1995). Cessation of mowing and raking will also have enhanced nutrient cycling as dead material is left to decompose in-situ returning nutrients to the soil. This intervention is likely to have had positive effects for insectivorous avifauna by increasing food sources in the remnant as invertebrates could colonise the moist and cool environment present in the decaying material on the forest floor.

Irrigation has been used in Pūtaringamotu since the 1970s, with an extensive system of 243 rotary spray heads each one metre above ground level established throughout Pūtaringamotu as of February 2000 (Chinn, 2006). This system was applied to benefit the shallow rooted vegetation present in the forest especially through the summer months when low rainfall and high temperatures can cause soil degradation restricting vegetative growth and lowering vegetative survival rates. As well as this, it addresses the lowering of water tables caused by installation of drainage systems in the surrounding urban environment. Since its inception there has been a noticeable increase in regeneration and seedling establishment rates and there appears to be an improvement in the health of mature *D. dacrydioides* (Molloy, 1995; Chinn, 2006; Norton, 2020).

Several exotic trees were planted in Pūtaringamotu by the Deans family when they settled in the area. In the 1970s the decision was made to remove these introduced exotic trees from the remnant. This was largely restricted to the perimeter where *Quercus robur* and other exotic trees were overshadowing the indigenous forest supressing growth and germination of indigenous seedlings. As well as this, the exotic trees had little value for protection of indigenous vegetation which had already established. Once exotic vegetation was removed replanting of margins and gaps was undertaken using indigenous vegetation grown in an onsite nursery (Molloy, 1995). Replanting with indigenous vegetation has helped prevent exotic vegetation from re-establishing and increased indigenous species presence.

A weed control programme was put in place to control weeds which had freely established from 1956 to 1959. Targeted species included *Sambucus nigra*, *Clematis vitalba*, *Lonicera japonica*, *Acer pseudoplatanus*, *Hedera helix*, *Hoheria populnea*, and *Rubus fruticosus*. Weeds continue to readily introduce into Pūtaringamotu from the surrounding urban landscape which allows for easy dispersal of unwanted vegetation into the remnant via vectors such as wind, birds, and humans. The focus of the weed control programme in recent years has been to eradicate major weed infestations and suppress unwanted vegetation in the forest to allow space to be inhabited by indigenous regeneration local to the Canterbury region. The increased establishment of indigenous vegetation and thickening forest floor layer will reduce space for weeds to colonise in the future (Molloy, 1995; Riccarton Bush Trust, 2015).

Formalisation of the walking tracks in Pūtaringamotu has been undertaken to reduce anthropogenic influences on the remnant. Prior to the formalisation of walking tracks several official tracks were available and many unofficial tracks had been created in the remnant by members of the public. Having multiple official and unofficial walking tracks increased occurrences of disturbance to flora and fauna via trampling and destruction. Alongside the formalisation of the walking tracks there has been a reduction of entry and exit points to a singular gate located near Riccarton House. The securing of boundaries has restricted the ability for members of the public to enter from residences surrounding the remnant and allowed for tracking of visitor numbers (Molloy, 1995; Norton, 2020).

The establishment of a 1.1 km pest proof fence surrounding Pūtaringamotu is the most recent management initiative undertaken with completion occurring in 2004 (Chinn, 2006; Burns, et al., 2012; Norton, 2018). Following its establishment an intensive pest eradication scheme was undertaken to remove mammalian pest species from the forest. This involved eradication of cats, possums, rats, mice, and hedgehogs from the fenced area (Moore, 2006). Its establishment allowed for eradication of pests rather than fluctuating pest numbers, but to continue to see positive effects the fence will need to be maintained indefinitely (Chinn, 2006; Burns, et al., 2012). This is because fences are pest resistant rather than pest proof (Innes, et al., 2012). To continue being effective adequate distance between tree branches and the fence are maintained to prevent pest movement across the fence, detection measurements including bait stations and tracking tunnels have been put in place to monitor pest breaches into Pūtaringamotu, and a rapid response plan is in place to control any breaches (Burns, et al., 2012; Riccarton Bush Trust, 2015; Pech & Maitland, 2016; Innes, et al., 2019). The impacts of establishing a pest proof fence have included prevention of grazing on the establishing understory and creation of a sanctuary free from predation for fauna. It is hoped that the removal of pest species will allow for the reversal of degradation of ecological processes within the confines of the present day to eventually allow for emergence of an ecosystem similar to that which would have once occurred across areas of the lower Canterbury Plains prior to anthropogenic influence (Burns, et al., 2012).

3 Vegetation

3.1 Introduction

Vegetation is an important component of biodiversity present in urban forest remnants acting as a refuge for flora and fauna (Crisp, Dickinson, & Gibbs, 1998; Wiser, Bellingham, & Burrows, 2001; Chytry, Schaminee, & Schwabe, 2011). To gain knowledge on how vegetation is changing over time long-term monitoring programmes can be put in place to allow for repeated measurements of vegetation to see if abundance, composition, and diversity change over time. The temporal study of vegetation allows inferences to be made on whether the goals/objectives of management in a particular remnant are being met (Hill, Fasham, Tucker, Shrewry, & Shaw, 2005). This information can be utilised to assess the success of management protocols, and depending on the outcomes appropriate management responses can be formulated to further improve vegetation biodiversity (Hill, Fasham, Tucker, Shrewry, & Shaw, 2005; Rose, 2012).

Vegetation in Pūtaringamotu has been a vastly studied biodiversity group, with the first records of species dating back to the 1870s (Molloy, 1995). Today Pūtaringamotu is the only remnant forest in Christchurch containing the original podocarp forest of the lower Canterbury Plains (Matapopore Charitable Trust, 2020). As a result of this, the remnant forest is isolated in space from significant sources of indigenous vegetation (Chinn, 2006). Management prior to the 1970s resulted in many species being lost from the remnant as mowing and raking and burning of leaf litter and woody material created a poor environment for indigenous vegetation to regenerate and flourish (Molloy, 1995; Norton, 2020). Introduction of ecologically based management from the 1970s has allowed for vegetation in the remnant to regenerate successfully leading to increased indigenous vegetation presence (Molloy, 1995).

The vegetation of Pūtaringamotu has undergone several historic modifications influencing the structure and composition of the present vegetation in the remnant forest. The vegetation of Pūtaringamotu was first influenced by accidental Māori burnings prior to the arrival of Europeans in New Zealand (McWethy, Whitlock, Wilmshurst, McGlone, & Li, 2009; Norton, 2020). More significant modification coincided with the arrival of European settlers, this is because Europeans cleared large areas of indigenous forests for timber and introduced exotic species causing widespread disturbance to the indigenous forest of New Zealand (Molloy, 1995; Norton, 2020). Within Pūtaringamotu the demand for timber caused half of the remaining remnant to be cleared from the 1850s to the 1900s, with a particular focus on the old growth trees *D. dacrydioides*, *P. taxifolia*, and *P. totara*. This left exposed forest edges which were later replanted using exotic trees which were thought to be useful for protection. Despite the good intention, these exotic trees tended to cause more issues for the indigenous remnant as they overshadowed established indigenous vegetation and smothered the growth of indigenous seedlings (Molloy, 1995). As well as this, mowing of the understory was undertaken damaging the surface roots of *D. dacrydioides* and preventing establishment of an understory layer. Since Armstrong's initial survey of vegetation in 1870 over 40 vegetative species have disappeared from Pūtaringamotu (Molloy, 1995), with the disappearances likely being a product of the rarity of the species and the initial mismanagement of the remnant forest.

The establishment of ecologically based management protocols from the 1970s onward allowed the vegetation of the remnant forest to flourish under less restrictive measures. The most significant management interventions for vegetation have included cessation of mowing and raking, allowing for decay of material in-situ, removal and replacement of exotic vegetation, control of weeds, irrigation, and establishment of a pest proof fence. Collectively these changes have improved vegetation due to the positive effects changes have had on growth and recovery. The cessation of mowing and raking has prevented damage to surface roots and allowed an understory to establish, weed control has left space for indigenous seedlings to grow unhindered, irrigation has benefited the shallow root system especially through warm and dry summers, and the pest proof fence has reduced browsing on vegetation. All these management protocols have worked in-situ to protect the remaining vegetative biodiversity present within the remnant forest.

Five vegetative structural composition units (Fig. 2) have been identified within Pūtaringamotu based on the dominant vegetation types in different areas of the remnant. The units, descriptions, and locations are as follows:

- Dense kahikatea forest
    - Dense stratum of emergent *D. dacrydioides* with occasional *E. hookerianus* over canopy of broadleaved trees
    - Located in centre of remnant with small enclave in the north,
- Broadleaved forest with scattered kahikatea
    - Broadleaved trees form a low canopy with scattered emergent *D. dacrydioides*
    - Located throughout the remnant,
- Kahikatea-cabbage tree forest
    - Dense *C. australis* trees alongside *D. dacrydioides* and occasional sedges and flaxes
    - Located in southern end of remnant,
- Dense broadleaved forest
    - Dense even canopy of *P. regius* and occasional *S. microphylla* (*D. dacrydioides* is absent)
    - Located near Kauri Street entrance,
- Cleared and replanted forest fringe
    - Planted broadleaved species along margins where exotic trees were removed
    - Located on edges of remnant (Molloy, 1995).

Analysing temporal changes in the vegetation of Pūtaringamotu is expected to give an indication of whether vegetation abundance, composition, and diversity has changed in the last 20 years. This will show the effects ecologically based management has had on vegetation 30 years on from the first introduction of proactive management protocols. Pūtaringamotu is isolated in space preventing incursion of new indigenous species but it continues to experience dynamic changes within the boundaries of the remnant, therefore it is hypothesised:

- Species richness will significantly decrease over the 20-year period,
- Shannon's index will significantly decrease over the 20-year period,
- Basal area will significantly increase over the 20-year period, and,
- Cover will significantly increase over the 20-year period.

This research will allow for an understanding of whether ecologically based management interventions have created fundamental changes in the vegetation of Pūtaringamotu. The purpose of this chapter is to test whether:

- Vegetation abundance has changed over the last 20 years,
- Vegetation composition has changed over the last 20 years, and,
- Vegetation diversity has changed over the last 20 years.

3.2 Methodology

3.2.1 Ecological Data Collection

Ten 10 m x 10 m permanent sample plots (Fig. 3) have been established in Pūtaringamotu since 2000. The permanent sample plots provide a representative sample of the entirety of the remnant forest having been established in all five vegetative structural composition units (Tab. 1). Sampling of vegetation in the permanent sample plots has occurred three times over the last 20 years, undertaken by Sina Hustead and Sarah McElera in 2000, Rima Herber in 2013, and David Norton and Georgia Sharp in 2020. The repeated sampling over a 20-year period has allowed for determination of temporal trends related to vegetation within Pūtaringamotu. The permanent sample plots were found using a map to find four wooden corner pegs with metal guards in the remnant.

Figure 3: Location of permanent sample plots in Pūtaringamotu.

Table 1: Vegetative structural composition units of plots.

Vegetative Structural Composition Unit	Plot Number
Dense kahikatea forest	4
Broadleaved forest with scattered kahikatea	1, 2, 5, 8
Kahikatea-cabbage tree forest	6, 7
Dense broadleaved forest	3
Cleared and replanted forest fringe	9, 10

Care was taken to ensure vegetation data was collected in a similar matter over all sampling periods to allow for consistency between years. At each plot, corners were marked with pink flagging tape for easy identification and measuring tapes were laid out to define the outer edges of the plot. Whilst taking measurements quadrants were used to ensure no vegetation was missed. Within each plot species were identified based on prior knowledge, diameter at breast height (DBH) was measured, and cover visually estimated. DBH was measured at 1.4 m on all vegetation with a DBH greater than 2 cm using a diameter tape, when required DBH was measured on each separate stem of an individual. Percentage cover was recorded from the centre of the plot for all vegetation deemed to fall within the boundaries using visual identification methods. It was separated into four height classes (Tab. 2) and seven abundance classes (Tab. 3). This provided a measure of the proportion of the surface covered by vegetation in the differing height classes (Damgaard, 2014). These methods were selected for data collection as they provide data for assessment of composition using the proxy basal area and abundance of species using cover.

Table 2: Height classes used for assessing vegetation cover.

Height Classes	Height (m)
Canopy	>12
Sub-canopy	3 - 12
Shrub	0.3 - 3
Ground	<0.3

Table 3: Abundance classes used for assessing vegetation cover.

Abundance Classes	Cover (%)
1	<1
2	1 - 5
3	6 - 10
4	11 - 25
5	26 - 50
6	51 - 75
7	76 - 100

Potential sources of error that may have arisen during fieldwork include incorrect identification of species, inconsistent measurement techniques, and difficulty determining boundaries. To lessen sources of error all measurements and observations were taken by observers over two days for each sampling period. Doing so reduced the likelihood of inconsistencies between plots as any observer bias will have been present across all plots for the specific year. Despite this it should be noted that observers changed between sampling periods which may have increased the level of inconsistency due to observer bias changing for each sampling period, this was reduced as much as possible by ensuring all observers had the same baseline knowledge of vegetation and measurement techniques (Milberg, Bergstedt, Fridman, Odell, & Westerberg, 2008; Kapfer, et al., 2017). Care was also taken by observers to minimise disturbance on the ground to reduce trampling of vegetation. Differences in measurement and observation techniques between sampling periods was reduced as much as possible by ensuring the same methods were used, despite this a level of uncertainty remains around the quality of historic data. For the purpose of this research, it has been assumed all historic data was true for the sampling period in which it was taken.

3.2.2 Data Analysis

The entirety of the data analysis for vegetation was conducted using the statistical software R (R Core Team, 2020) using the Lattice (Sarkar, 2008), ggplot2 (Wickham, 2016), and Vegan (Oksanen, et al., 2019) packages. To visualise differences between the samples clustered column charts have been produced and variables have been assessed to see if differences are apparent. It has been assumed that the level of statistical significance is $\alpha = 0.05$, hence P-values less than or equal to alpha represent statistically significant differences. Studies of vegetation typically use ecological indices to assess how an ecosystem is changing over time (Magurran, 1998; Purvis & Hector, 2000; The Royal Society, 2003). For this research, the following indices have been used to gain an understanding of how vegetation in Pūtaringamotu has changed over the last 20 years.

3.2.2.1 Ecological Indices

<u>Species Richness:</u> Total number of species observed

Species richness is a measurement of the number of species present in a community and is the most common measure of ecological diversity (Magurran, 1998). It should be recognised that gaining an unbiased measurement of species richness is impossible as there will be species absent from plots which are present in the community (Palmer, 1990). Palmer (1990) found that the correlation between species observed in plots and the true value of species richness in a community is 0.97, as this value is close to 1 it is possible to compare the number of species observed if sampling remains consistent between different periods. Within Pūtaringamotu species richness was recorded by observing the species present in each plot over the three sampling periods and depicted as a clustered column chart to visualise the changes in species numbers over the different sampling periods. As well as this, a column chart of species richness for weed species has been produced for the 2020 sampling period to visualise where weed incursion is occurring within Pūtaringamotu.

<u>Shannon's Index:</u> $(\pi) * \ln(\pi)$
As π is unknown it has been estimated as n_i / N where n_i = number of individual species and N = total amount of species

Shannon's index provides a measure of heterogeneity by combining species richness and species evenness into a single measure (Chao & Shen, 2003). The assumption is made that all species which are present in the wider population are present within the plots which are sampled. As previously indicated, it is impossible to know if this is true for the community therefore it should be noted sources of error will increase as the proportion of species from the community decreases within sampled plots (Magurran, 1998; Chao & Shen, 2003). Shannon's index has been depicted as a clustered column chart to visualise the differences apparent between different sampling periods.

Cover: Importance value = ($\log_{10}$ * height class (+1)) * midpoint of cover class

Cover is used to provide a measure of species abundance (Chiarucci, Wilson, Anderson, & De Dominicis, 1999). For this research, analysis of cover has been undertaken using a summed importance value for each species in each plot. Additionally, the canopy, sub-canopy, shrub, and ground layer have been added together to represent a single importance value for canopy cover in each plot. Cover abundance in Pūtaringamotu has been depicted using a clustered column chart to allow for comparison of differences between the three different sampling periods.

Basal Area: $\pi * r^2$

Basal area provides a measurement of how a forest community is thickening and can show the total growth of vegetation over time (Elledge & Barlow, 2010). For this research, basal area has been converted from individually measured DBH into a total basal area and converted into m^2/ha for each plot. Basal area has been depicted as a clustered column chart to visualise whether the basal area of Pūtaringamotu has increased or decreased over the 20-year period from 2000 to 2020. This has been conducted separately for all species and all species minus *D. dacrydioides*. This was done as *D. dacrydioides* contributes significantly to basal area and therefore may obscure the true difference in basal area between permanent sample plots.

3.2.2.2 Analysis of Variance and Pairwise Comparison

Following the calculation of ecological indices analysis of variance (ANOVA) was run to assess if significant changes were apparent between the different sampling periods, and between different vegetative structural composition units. In cases where a significant difference was returned further analysis was undertaken by pairwise comparison using Tukeys Test to visualise where differences were apparent.

3.2.2.3 Ordination

Lastly, non-metric multi-dimensional scaling (NMDS) has been used separately for basal area and cover to condense large amounts of data into a low dimensional ordination space detailing the plots present in Pūtaringamotu. NMDS provides an unconstrained ordination for the purpose of testing the relationships between permanent sample plots located in Pūtaringamotu (Minchin, 1987). This allowed the data to be visualised in an easy manner as similar entities are placed close together and dissimilar entities are placed further apart along arbitrary axes providing a summary of the abundance and composition patterns present in Pūtaringamotu. The NMDS plots were produced using the R metaMDS function available in the Vegan package using the Bray-Curtis distance matrix. This function runs through an iterative process to select the model with the lowest stress possible (Bray & Curtis, 1957; Holland, 2019; Oksanen, et al., 2019). Using the Vegan package, a goodness of fit model has been created to provide a stress value for each NMDS, stress values of 0 suggest the data fits a model perfectly (Quinn & Keough, 2002), but any stress value less than 5 is said to provide a good representation of data which cannot be misconstrued (Clarke, 1993). Where significant differences were found in ordinations an analysis of similarities test (ANOSIM) was undertaken to test the differences between groups. ANOSIM was run in R as a function of the Vegan package to provide the ANOSIM statistic 'R'. 'R' values range from 0 to 1, with high values suggesting dissimilarity between ecological groups and low values suggesting similarity between ecological groups (Clarke, 1993).

3.3 Results and Discussion

3.3.1 Species Richness

3.3.1.1 Tree Species

ANOVA for species richness shows no significant difference between the number of species present in plots between the different sample periods ($F = 0.04$, $df = 2$, $P = 0.96$). When conducting ANOVA for the differing vegetative structural composition units a significant difference is apparent ($F = 3.95$, $df = 4$, $P = 0.05$). Tukeys test indicates that significant differences are apparent between dense kahikatea forest and dense broadleaved forest, as well as between dense broadleaved forest and the cleared and replanted forest fringe. This reveals that dense broadleaved forest has significantly more species present than dense kahikatea forest and the cleared and replanted forest fringe (Tab. 4) as would be expected for the different categories of forest types present.

Table 4: Mean species richness in vegetative structural composition units. Letters indicate the Tukey groupings, means with the same letter are not significantly different.

Vegetative Structural Composition Unit	**Mean + Standard Deviation**
Dense kahikatea forest	4.7 ± 0.57^{A}
Broadleaved forest with scattered kahikatea	6.3 ± 1.09^{AB}
Kahikatea-cabbage tree forest	7.3 ± 1.61^{AB}
Dense broadleaved forest	8.0 ± 1.00^{B}
Cleared and replanted forest fringe	4.8 ± 1.26^{A}

Between 2000 and 2020 plots 1, 2, 3, 5, and 8 have shown an overall decrease in species richness, plots 6, 7, and 10 have shown an overall increase in the number of species present, and plots 4 and 9 have remained static in the number of species in the plot. The largest change in species richness was observed in plot 6 which had an increase of 4 species between 2000 and 2020 (Fig. 4). Decreases in species richness indicate some species did not have the adaptive potential to survive in the environmental conditions of the plots (Eizaguirre & Baltazar-Soares, 2014). In juxtaposition, plots where species richness has increased show that regeneration is naturally occurring in Pūtaringamotu.

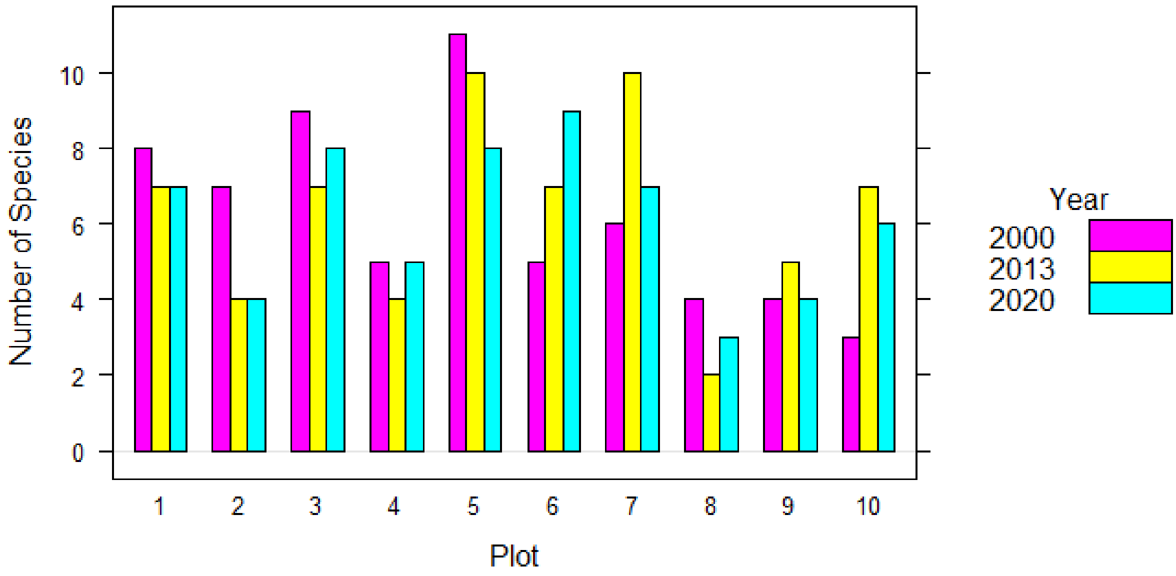

Figure 4: Clustered column chart of species richness present in permanent sample plots.

3.3.1.2 Weed Species

Incursion of weed species into Pūtaringamotu was sampled in 2020. The largest number of weed species occurred in the cleared and replanted forest fringe vegetative structural composition unit at 13 species, while no weed species were found in the dense broadleaved forest vegetative structural composition unit (Fig. 5). This indicates weed incursion is occurring predominately along the edges of the remnant (Fig. 3), as would be expected as the forest edge is closest to the surrounding urban matrix which increases the likelihood of incursion events and has more light available to facilitate weed survival (Rowley, Edwards, & Kelly, 1993; McAlpine, Lamoureaux, & Westbrooke, 2015).

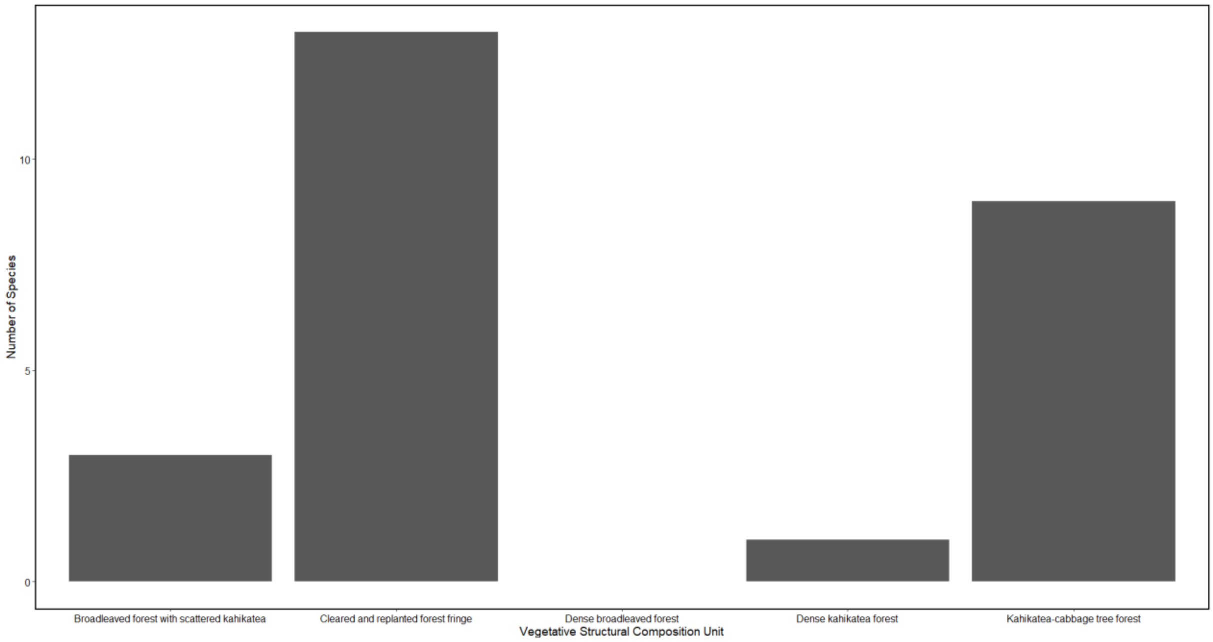

Figure 5: Column chart of species richness present in vegetative structural composition units (2020).

3.3.2 Shannon's Index

When running ANOVA for Shannon's index no significant difference in heterogeneity was detected between the different sample periods (F = 0.7, df = 2, P = 0.93). Within the vegetative structural composition units, no significant difference in heterogeneity was found when conducting ANOVA (F =3.59, df = 4, P = 0.06). Therefore, all plots in Pūtaringamotu can be said to have a similar level of heterogeneity across all vegetative structural composition units (Tab. 5).

Table 5: Mean Shannon's index in vegetative structural composition units. Letters indicate the Tukey groupings, means with the same letter are not significantly different.

Vegetative Structural Composition Unit	**Mean + Standard Deviation**
Dense kahikatea forest	1.4 ± 0.14^{A}
Broadleaved forest with scattered kahikatea	1.3 ± 0.17^{A}
Kahikatea-cabbage tree forest	1.6 ± 0.28^{A}
Dense broadleaved forest	1.6 ± 0.30^{A}
Cleared and replanted forest fringe	0.9 ± 0.33^{A}

Between 2000 and 2020 plots 4, 6, 7, and 10 have shown an overall increase in heterogeneity, while plots 2, 3, 5, and 8 have shown an overall decrease in heterogeneity. The greatest Shannon's index value occurred in plot 5 in 2000 at H' = 1.96 and the lowest Shannon's index value occurred in plot 8 in 2013 at H' = 0.25. Plots 8 and 9 can be seen to have lower Shannon's index values across all three sampling periods compared to other plots (Fig. 6), the heterogeneity of these plots sits outside the expected ecological boundaries of H' = 1.5 - 3.5 for all three sampling periods (Magurran, 1998).

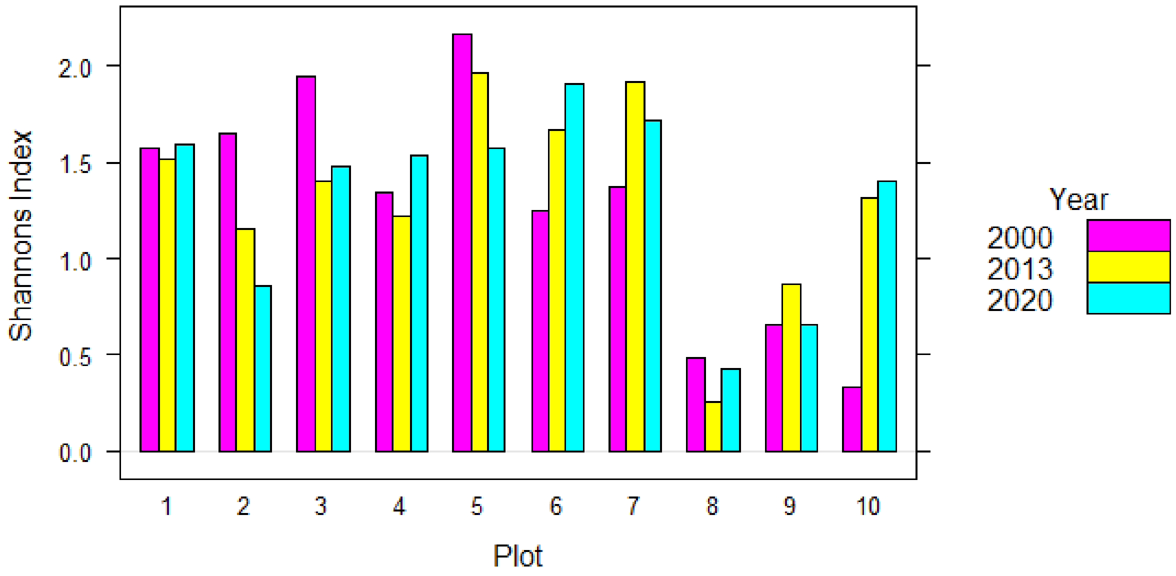

Figure 6: Clustered column chart of Shannon's index present in permanent sample plots.

3.3.3 Basal Area

ANOVA for basal area detected no significant difference in growth between the different sample periods (F = 0.21, df = 2, P = 0.81). When undertaking ANOVA for the different vegetative structural composition units a significant difference was found (F = 9.01, df = 4, P = 0.000001). Tukeys test indicates that significant differences are apparent between all vegetative structural composition units except broadleaved forest with scattered kahikatea and the cleared and replanted forest fringe, and dense broadleaved forest and the cleared and replanted forest fringe (Tab. 6).

Table 6: Mean basal area in vegetative structural composition units (all species). Letters indicate the Tukey groupings, means with the same letter are not significantly different.

Vegetative Structural Composition Unit	**Mean + Standard Deviation**
Dense kahikatea forest	132.1 ± 9.68^{A}
Broadleaved forest with scattered kahikatea	49.8 ± 2.28^{B}
Kahikatea-cabbage tree forest	77.5 ± 9.04^{C}
Dense broadleaved forest	21.9 ± 7.44^{D}
Cleared and replanted forest fringe	35.4 ± 7.13^{BD}

Between 2000 and 2020 the basal area of plots 1, 3, 4, 9, and 10 have increased, while plots 2, 5, 6, 7, and 8 have decreased. Over the 20-year period the largest increase of growth occurred in plot 1 which grew 25 m^2/ha and the largest decrease in basal area occurred in plot 7 which decreased by 22 m^2/ha. Plot 4 had the largest basal area in 2020 changing from 122 m^2/ha in 2000, 141 m^2/ha in 2013, to 133 m^2/ha in 2020 (Fig. 7).

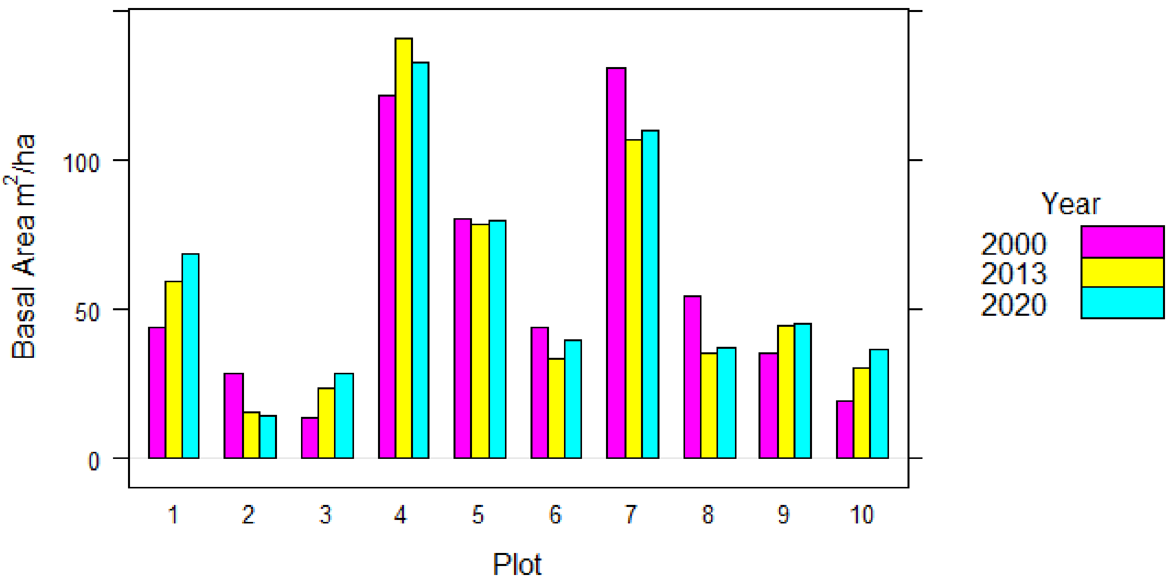

Figure 7: Clustered column chart of basal area (all species) present in permanent sample plots.

As *D. dacrydioides* contributed significantly to basal area it was decided to remove the species from the sample to see if differences occurred in the remaining species. ANOVA did not display a significant difference between sampling periods (F = 0.20, df = 2, P = 0.82), and also did not display a significant difference between vegetative structural composition units (F = 2.31, df = 4, P = 0.15). This indicates the prior differences were driven by the presence of *D. dacrydioides* (Tab. 6). Removal of *D. dacrydioides* has resulted in the means of the vegetative structural composition units dropping significantly for dense kahikatea forest, broadleaved forest with scattered kahikatea, and kahikatea-cabbage tree forest with differences of 104 m^2/ha, 23 m^2/ha, and 42 m^2/ha respectively (Tab. 6, Tab. 7).

Table 7: Mean basal area in vegetative structural composition units (D. Dacrydioides omitted). Letters indicate the Tukey groupings, means with the same letter are not significantly different.

Vegetative Structural Composition Unit	**Mean + Standard Deviation**
Dense kahikatea forest	28.3 ± 1.05^A
Broadleaved forest with scattered kahikatea	26.8 ± 2.76^A
Kahikatea-cabbage tree forest	35.3 ± 8.22^A
Dense broadleaved forest	21.9 ± 7.44^A
Cleared and replanted forest fringe	35.4 ± 7.08^A

The difference in basal area when removing *D. dacrydioides* is apparent when viewing the clustered column charts (Fig. 7, Fig. 8) with the removal of *D. dacrydioides* significantly decreasing the basal area of plots (Fig. 8). Between 2000 and 2020 the basal area of plots 1, 3, 4, 5, 9, and 10 increases while the basal area of plots 2, 6, 7, and 8 decreases (Fig. 8). The difference in total basal area between years can be attributed to the growth rates of vegetation located within the plots or to the dieback of vegetation in cases where basal area has decreased.

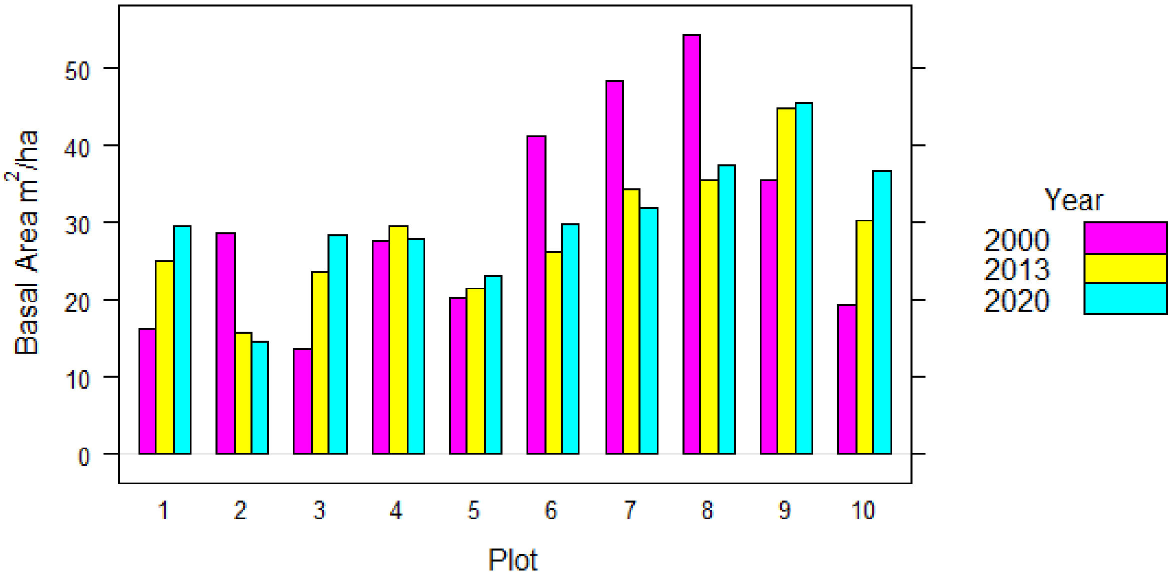

Figure 8: Clustered column chart of basal area (D. Dacrydioides omitted) present in permanent sample plots.

3.3.4 Cover

When conducting ANOVA for cover no significant differences in abundance were found between the different sample periods (F = 1.22, df = 2, P = 0.32). When doing ANOVA for the different vegetative structural composition units a significant difference was found (F = 6.99, df = 4, P = 0.01). As a result of the differences in vegetative structural composition units a Tukeys test was undertaken to see where differences occurred. It was found that dense kahikatea forest and kahikatea-cabbage tree forest, dense kahikatea forest and the cleared and replanted forest fringe, kahikatea-cabbage tree forest and dense broadleaved forest, and dense broadleaved forest and the cleared and replanted forest fringe were significantly different from each other (Tab. 8). These differences are likely to occur as some plots contain a higher proportion of dense trees which contribute significantly to cover. As well as this, the cleared and replanted forest fringe vegetation has not had as long to mature since the replanting of indigenous vegetation along the edge of the remnant in the 1970s, meaning the vegetation of this structural composition unit is of a different age to the other vegetative structural composition units, resulting in the cleared and replanted forest fringe generally having less cover than older structural composition units within the remnant.

Table 8: Mean cover in vegetative structural composition units. Letters indicate the Tukey groupings, means with the same letter are not significantly different.

Vegetative Structural Composition Unit	Mean + Standard Deviation
Dense kahikatea forest	330.1 ± 65.65^{A}
Broadleaved forest with scattered kahikatea	286.4 ± 20.05^{AB}
Kahikatea-cabbage tree forest	189.3 ± 36.21^{B}
Dense broadleaved forest	361.5 ± 45.67^{A}
Cleared and replanted forest fringe	200.2 ± 58.73^{B}

Between 2000 and 2020 plots 1, 2, 3, 5, 6, 7, and 10 have shown an overall increase in abundance while plots 4, 8, and 9 have shown an overall decrease in abundance. Over the 20-year period more plots have increased in cover than decreased suggesting the remnant forest is continuing to increase in abundance possibly due to the vegetation continuing to mature within the remnant. Decreases which have occurred in three plots may have been incited by dieback of vegetation creating gaps, in these cases the cover of plots would decrease as individuals will have been lost from the plot.

The largest change in cover occurred in plot 10 which increased from 100 in 2000 to 331 in 2020. This was also the plot that had the highest amount of variability going from a cover value of 100 in 2000 before dropping to 36 in 2013, and rising to 331 in 2020 (Fig. 9). This may have occurred as changes in cover occur rapidly on the forest edge where there is more light available to facilitate growth and also more wind effects which can result in mortality. Alternatively, it could indicate that there is an observer bias present in plot 10 between the three sampling periods (Milberg, Bergstedt, Fridman, Odell, & Westerberg, 2008; Kapfer, et al., 2017).

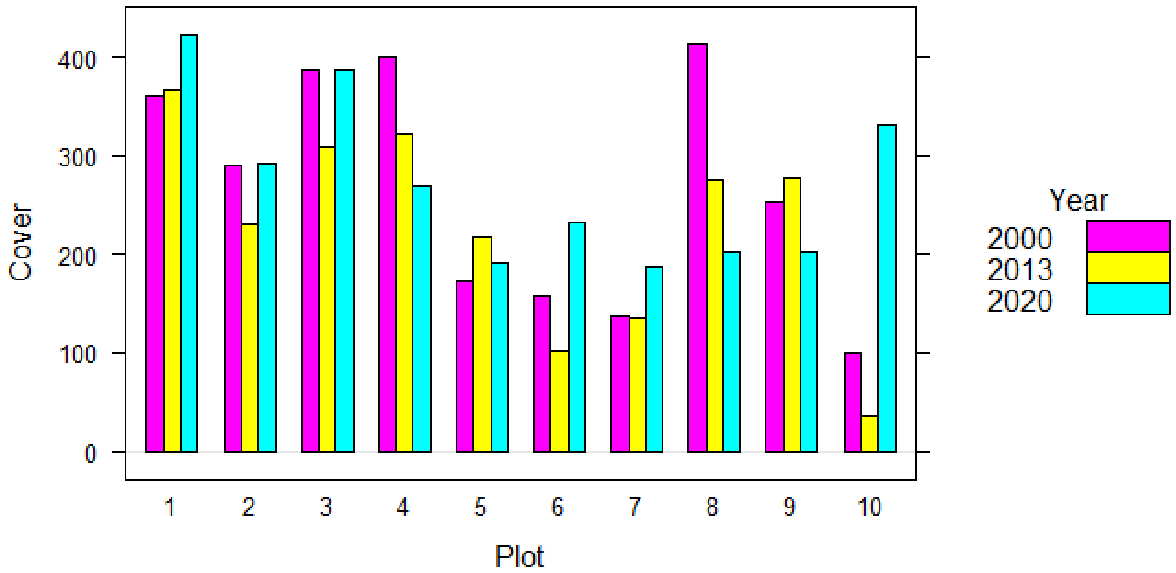

Figure 9: Clustered column chart of cover present in permanent sample plots.

3.3.5 Ordination

3.3.5.1 Basal Area

NMDS was undertaken to compare how the basal area of permanent sample plots in Pūtaringamotu has shifted over the last 20-years. The NMDS ordination provides a good representation of basal area similarity and dissimilarity, with a low two-dimensional stress value of 1.19. Typically, the same plots are located fairly close to each other for all three sampling periods, with the largest shift occurring in plot 2 and the smallest shift occurring in plot 8 (Fig. 10). The ordination values appear separated in the NMDS space (Fig. 10), but no significant difference occurs between years (F = 1.05, P = 0.47) or plots (F = 1.02, P = 0.49).

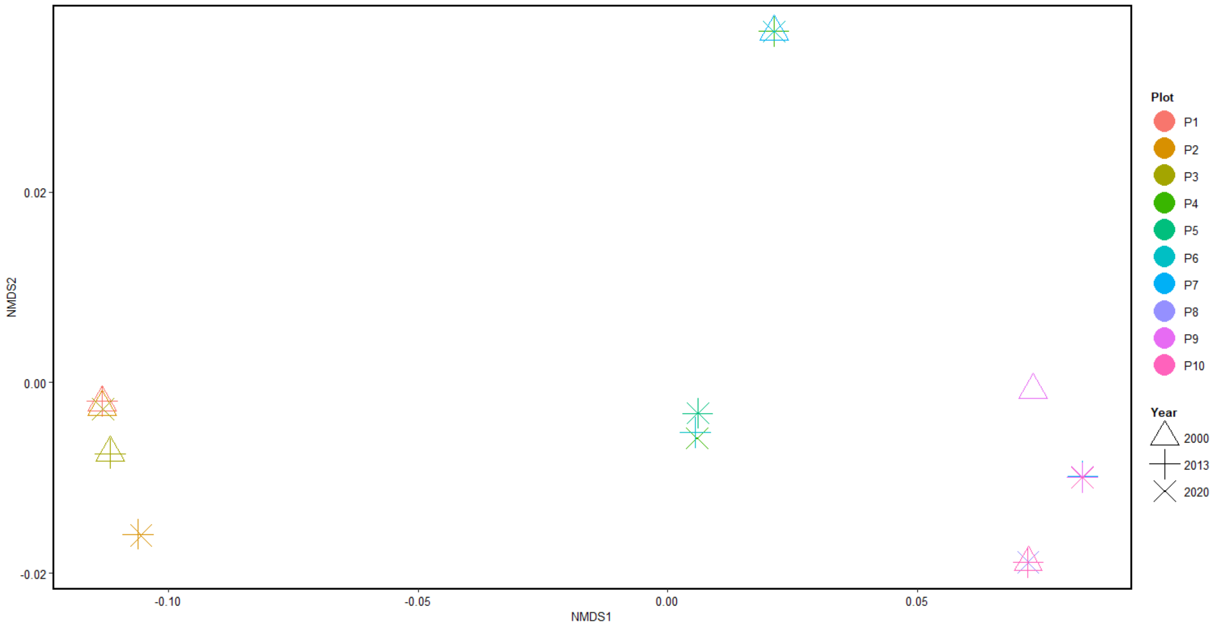

Figure 10: NMDS ordination of basal area in permanent sample plots (stress =1.19).

3.3.5.2 Cover

NMDS was undertaken to compare how the cover of permanent sample plots in Pūtaringamotu has shifted over the 20-year period between 2000 and 2020. The NMDS ordination provides a good representation of cover similarity and dissimilarity, with a low two-dimensional stress value of 0.082. Generally, the same plots are located fairly close to each other for all three sampling periods, with the largest shift occurring in plot 9 and the smallest shift occurring in plot 3 (Fig. 11). Whilst the ordination appears visually separated within the NMDS space (Fig. 11), no significant difference was found between years (F = 1.22, P = 0.52). There is however a significant difference between plots (F = 1.03, P = 0.04). This is confirmed by the ANOSIM result of R = 0.64, P = 0.001 which indicates slight dissimilarity between plots as the R value sits above 0.5.

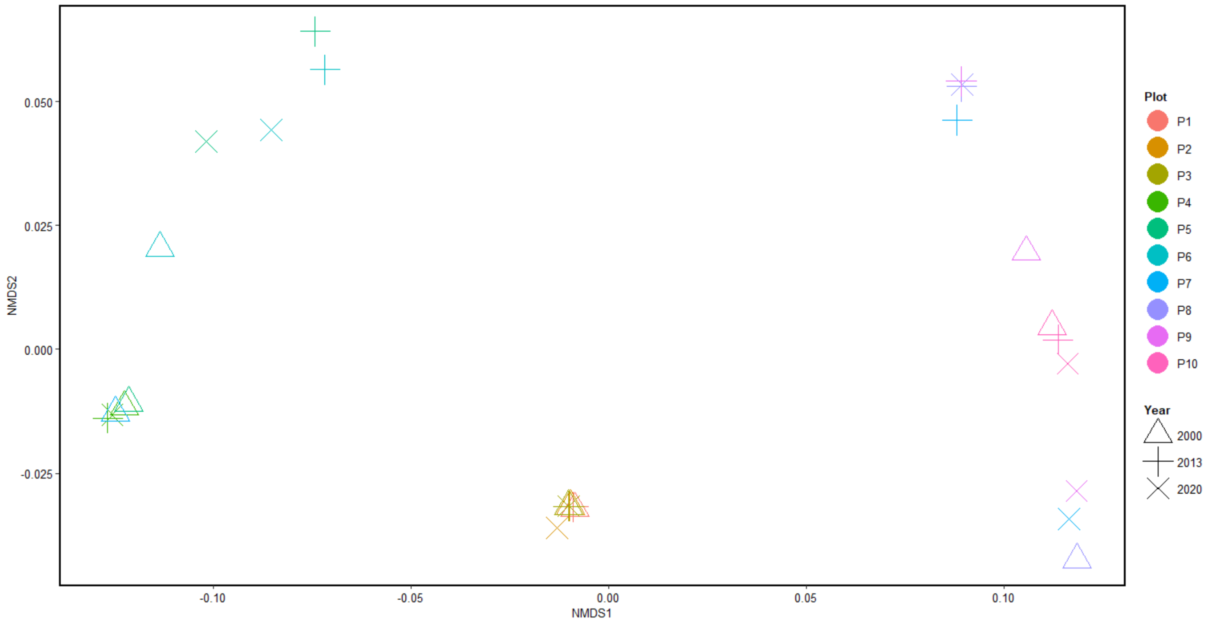

Figure 11: NMDS ordination of cover in permanent sample plots (stress = 0.082).

3.4 Summary

This research on vegetation in Pūtaringamotu assessed a 20-year period of vegetative change from 2000 to 2020 as a means to see whether vegetation abundance, composition, and diversity had changed in this timeframe. Ecological indices have been used as proxies for this research with cover being used as a measure of abundance, basal area being used as a measure of composition, and species richness and Shannon's index providing measures of diversity. Results from this research have found no significant differences between the three sampling periods have occurred. This indicates that fundamental changes to vegetation are yet to occur within Pūtaringamotu. Whilst fundamental changes are yet to occur as indicated by the lack of significant differences between years, changes which are not statistically significant are occurring for vegetative abundance, composition, and diversity.

The hypothesis that cover will significantly increase is rejected as no significant difference is found between sampling periods. Although, it was found only three of ten plots did not experience an increase in cover over the 20-year timeframe indicating changes are occurring which are not statistically significant. The hypothesis that basal area will significantly increase is rejected as no significant difference is found between the sampling periods, this occurs for assessment when all species are included and when *D. dacrydioides* is omitted. It was found that when *D. dacrydioides* is omitted more plots increase in basal area than decrease despite not showing a significant difference between sampling periods. The hypothesis that species richness will significantly decrease is rejected as no significant difference was found between sampling periods. Although, the species richness of plots has changed with more plots decreasing in species richness than increasing over the 20 years suggesting changes are still occurring that are not significant. The hypothesis that Shannon's index will significantly decrease is rejected as no significant differences are found between sampling periods. The Shannon's index in plots has changed over the 20-year period showing changes are occurring between sampling periods that are not statistically significant.

Results found for differences in vegetative structural composition units suggest that Pūtaringamotu is still broken into distinct structural composition units with significant differences found between some units for species richness, basal area of all species, and cover. However, significant differences were not found between vegetative structural composition units for Shannon's index or basal area when *D. dacrydioides* was omitted. This suggests the heterogeneity of Pūtaringamotu is statistically similar across all vegetative structural composition units and the basal area is statistically similar across all units when the largest contributor to basal area is removed. This suggests Pūtaringamotu may become more uniform over an extended timeframe.

Overall, the assessment of whether vegetation abundance, composition, and diversity has changed in the last 20 years in Pūtaringamotu found that significant differences are not occurring. Although, there are indicators present that suggest non-significant changes have occurred over the 20-year timeframe. It is thought the timeframe for this research may have been too short to see the true effects ecologically based management will have on vegetation, as the response of vegetation to changes in management may take a longer length of time to occur (Bakker, Willems, & Zobel, 1996). Therefore, it is recommended the permanent sample plots continue to be remeasured on a regular basis to allow future research to be conducted on how vegetation in Pūtaringamotu continues to change so to assess if fundamental changes are occurring as a result of the ecologically based management interventions over a longer time period.

4 Avifauna

4.1 Introduction

Avifauna are an important component of biodiversity in urban forests as they facilitate multiple ecological processes including seed dispersal, pollination, and ecosystem engineering (Whelan, Wenny, & Marquis, 2008). Long-term monitoring of avifauna can be undertaken using repeated measurements to gain an understanding of how avifaunal abundance, composition, and diversity are changing in an environment over an extended timeframe. Temporal studies of avifauna allow inferences to be made on whether the goals/objectives for a particular remnant are being met by the management protocols being utilised. In cases where management is found to be insufficient for achieving goals/objectives new management responses can be formulated to allow avifaunal biodiversity to develop (Bibby, Burgess, Hill, & Mustoe, 2000; Hill, Fasham, Tucker, Shrewry, & Shaw, 2005; Hartley, 2012; Hartley & Greene, 2012).

The first scientific study on the avifauna of Pūtaringamotu was conducted in the 1980s after ecological management was first implemented (O'Donnell, 1995), prior to this historical data on bird species was limited to written accounts of the people settling in the Canterbury region (Molloy, 1995). Presently, few indigenous birds and many exotic birds are found in Pūtaringamotu as a result of historic influences. Little information is known about the changes to avifauna prior to European arrival, but it is likely indigenous bird species have declined in Pūtaringamotu since anthropogenic change first occurred. Marked decline would have occurred with the arrival of mammalian predators as New Zealand’s indigenous avifauna did not evolve alongside predation from mammals and were therefore ill-equipped to deal with the threat (McGlone, 1989; Duncan & Blackburn, 2004). As well as this, the felling of indigenous forests for timber and agricultural space would have further isolated the remnant (Chinn, 2006; Ewers, et al., 2006; Campbell-Hunt, 2008) limiting chances for indigenous birds to move along linkage corridors (Diamond, 1984; O'Donnell, 1995). In juxtaposition, exotic birds characteristic of urban areas have steadily increased in Pūtaringamotu since their introduction as they are able to readily move between the remnant and the surrounding urban matrix (O'Donnell, 1995; Van Heezik, Symth, & Mathieu, 2008).

Management in Pūtaringamotu prior to the 1970s would have reduced the probability of avifauna surviving in the remnant. This is because food sources such as seeds and invertebrates were removed when leaf litter was mown, raked, and burnt reducing the ability for birds to feed in the remnant. In addition, this management would have also disturbed ground nesting species. Introduction of ecologically based management from the 1970s enriched the environment of Pūtaringamotu for avifauna by improving the vegetation as previously detailed in chapter 3. Other beneficial changes related to management have included the cessation of mowing and raking, allowing for decay of material in-situ, and the establishment of a pest proof fence. As a result of the cessation of mowing and raking and allowing for decay of material in-situ bird species were able to forage for seeds and invertebrates in the leaf litter layer which increased the availability of food sources in the remnant. The most significant change instigated by management was the establishment of a pest proof fence surrounding the entirety of Pūtaringamotu. This is highly significant for avifauna as the exclusion of pests from the remnant created a zone free from the threat of predation for avifauna (Burns, et al., 2012). This will have had the benefit of increasing individual bird numbers as lack of predation has been found to increase hatching, fledging, and breeding success (Smith, Pullin, Stewart, & Sutherland, 2010).

Analysing temporal changes in the avifaunal abundance, composition, and diversity in Pūtaringamotu is expected to provide an indication of the impact of ecologically based management over the last 15 years. This will show the effect ecologically based management has had on avifauna 35 years onward from the first introduction of proactive management measures. Pūtaringamotu is isolated in space (Chinn, 2006) and surrounded by an urban matrix therefore the response of indigenous and exotic avifauna is expected to differ (Chance & Walsh, 2006; Van Heezik, Symth, & Mathieu, 2008), hence, it is hypothesised:

- Overall species richness will significantly increase over the 15-year period,
- Overall Shannon's index will significantly increase over the 15-year period, and,
- Significant differences will be apparent between indigenous and exotic specimen over the 15-year period.

This research will allow for an understanding of whether ecologically based management interventions have created fundamental changes in the avifauna of Pūtaringamotu. The purpose of this chapter is to test whether:

- Avifauna abundance has changed over the last 15 years,
- Avifauna composition has changed over the last 15 years, and,
- Avifauna diversity has changed over the last 15 years.

4.2 Methodology

4.2.1 Ecological Data Collection

Monthly five-minute bird counts were undertaken on three occasions during the entire 15-year period in Pūtaringamotu, with sampling occurring in 2004/2005, 2008/2009, and 2018/2019. All observations were conducted by Andrew Crossland of Christchurch City Council, with both visual sightings and aural observations recorded. The entirety of the remnant forest was captured for each sampling period, with ten five-minute bird counts taking place along a transect of 810 m (Fig. 12). The repeated sampling over a 15-year period has allowed for determination of temporal trends related to avifauna in Pūtaringamotu.

Figure 12: 810 m transect (yellow) taken for Pūtaringamotu five-minute bird counts.

Care was taken to ensure data was collected in a similar matter over all sampling periods to minimise variability between years, with all three sampling periods using the five-minute bird count method detailed in Dawson & Bull (1975). Five-minute bird counts are carried out by an observer who remains at a single point for a five-minute duration recording every individual bird species that is seen visually or heard audibly (Hartley & Greene, 2012). For the purpose of this research, unbounded five-minute bird counts were conducted, in that, all birds that were seen or heard over the five-minute period were recorded regardless of distance from the observer (Hartley, 2012). The five-minute bird counts undertaken in Pūtaringamotu avoided the periods of dawn and dusk when birds are most conspicuous to remove the confounding variable of heightened avifauna activity at these times, which may have increased the count of individuals (Aschoff, 1966; Dawson & Bull, 1975; Robbins, 1981). As well as this, the monthly avifauna counts were all undertaken at the same time of day and only in fine weather so to keep environmental variables as consistent as possible (Bibby, Burgess, Hill, & Mustoe, 2000; Hartley & Greene, 2012).

Potential sources of error that may have arisen in fieldwork include incorrect identification of species, disturbance effects, and counting of the same individual multiple times (Dawson & Bull, 1975; Rosenstock, Anderson, Giesen, Leukering, & Carter, 2002). To minimise sources of error all observations of avifauna were undertaken by the same observer for all sampling periods. Doing so reduced the likelihood of inconsistencies between months and years as any observer bias will have been present across all samples (McArthur, Harvey, & Flux, 2013). Care was taken by the observer to minimise disturbance effects when walking through the remnant forest, this was done by walking slowly and quietly along the transect to reduce the chance of disturbing avifauna present in Pūtaringamotu. This had the added benefit of ensuring the observer was able to hear quiet bird calls. Lastly, to lessen the chance that individual birds were counted multiple times within the same five-minute period, individuals were only recorded if it was obvious they had not already been counted and travelled to a new location in the five-minute period (Dawson & Bull, 1975).

4.2.2 Data Analysis

The entirety of the data analysis for avifauna was conducted using the statistical software R (R Core Team, 2020), utilising the package ggplot2 (Wickham, 2016). To visualise differences in avifauna between sampling periods stacked column charts have been produced and variables have been assessed to view if significant differences are apparent. For the entirety of the analysis the level of statistical significance has been assumed to be $\alpha = 0.05$, therefore P-values less than or equal to alpha represent statistically significant differences. Ecological indices including species richness and Shannon's index have been used to assess the avifauna of Pūtaringamotu. As well as this, indigenous and exotic birds (Tab. 9) have been analysed to see if changes have occurred in the two groups in the last 15 years in Pūtaringamotu. It should be noted that this research has compiled both endemic and native species into a single category called indigenous avifauna.

Table 9: Indigenous and exotic avifauna found in Pūtaringamotu (New Zealand Birds Online, 2013).

Species	**Scientific Name**	**Indigenous / Exotic**
Bellbird	*Anthornis melanura*	Indigenous
Blackbird	*Turdus merula*	Exotic
California Quail	*Callipepla californica*	Exotic
Chaffinch	*Fringilla coelebs*	Exotic
Dunnock	*Prunella modularis*	Exotic
Fantail	*Rhipidura fuliginosa*	Indigenous
Goldfinch	*Carduelis carduelis*	Exotic
Greenfinch	*Carduelis chloris*	Exotic
Grey Warbler	*Gerygone igata*	Indigenous
House Sparrow	*Passer domesticus*	Exotic
Kereru	*Hemiphaga novaeseelandiae*	Indigenous
Kingfisher	*Todiramphus sanctus*	Indigenous
Magpie	*Gymnorhina tibicen*	Exotic
Redpoll	*Carduelis flammea*	Exotic
Rock Pigeon	*Columba livia*	Exotic
Shining Cuckoo	*Chrysococcyx lucidus*	Indigenous
Silvereye	*Zosterops lateralis*	Indigenous
Song thrush	*Turdus philomelos*	Exotic
Starling	*Sturnus vulgaris*	Exotic
Welcome swallow	*Hirundo neoxena*	Indigenous
Yellowhammer	*Emberiza citrinella*	Exotic

4.2.2.1 Ecological Indices

Species Richness: total number of species observed

Species richness is a measurement of the number of species present in a community. It should be recognised that it is impossible to gain an unbiased measurement of species richness as species which are in the community may be absent from the five-minute bird counts (Palmer, 1990; Anderson, 2001). Despite this, Palmer (1990) found the correlation between species observed and the true value of species richness to be 0.97, as this value is close to 1 it has been assumed that species richness can be compared between sampling periods if sampling remains consistent. Within Pūtaringamotu species richness was calculated for each sampling period as the number of species observed. This was depicted as a column chart to visualise changes in species numbers over the different sampling periods.

Shannon's Index: $(\pi) * \ln(\pi)$
As π is unknown it has been estimated as n_i / N where n_i = number of individual species and N = total amount of species

Shannon's index provides a measure of heterogeneity by combining species richness and species evenness into a single measure (Chao & Shen, 2003). For this index, an assumption is made that all species which are present in the avifauna of Pūtaringamotu are present in the five-minute bird counts. As previously indicated this is unlikely to occur, therefore sources of error will increase as the proportion of species in the community decreases in the five-minute bird counts (Chao & Shen, 2003). Shannon's index has been depicted as a column chart to see the differences that are apparent between different sampling periods.

4.2.2.2 Analysis of Variance

After ecological indices were obtained calculation of the analysis of variance (ANOVA) was undertaken to assess if significant differences were apparent between the different sampling periods, as well as between indigenous and exotic avifauna.

4.2.2.3 Five-Minute Bird Counts

Finally, line graphs of the yearly totals for five-minute bird counts of 15 prominent individual species, chosen by Andrew Crossland, have been analysed to assess differences between years. Line graphs have been produced separately for exotic species and indigenous species to see the differences apparent between different sampling periods. Where large differences in bird counts exist between species the most abundant species has been removed, e.g. silvereye (Fig. 15), and graphs have been reproduced so to rescale graphs to visualise the differences between sampling periods for less abundant species.

4.3 Results and Discussion

4.3.1 Species Richness

ANOVA shows that there is no significant difference in species richness between years ($F = 3.00$, $df = 2$, $P = 0.25$). Although, between 2004/2005 and 2018/2019 the total number of avifauna species observed has increased from 16 in 2004/2005 to 21 in 2018/2019 (Fig. 13). In the same period indigenous avifauna have increased from 6 species to 8 species and exotic avifauna have increased from 10 species to 13 species (Fig. 13). This increase in the number of species suggests Pūtaringamotu is being utilised by new species, but it should be noted that avifauna may be using Pūtaringamotu as a linkage corridor rather than establishing in the remnant (Thomas, 1991). Future data collection will be able to give more understanding of whether new species are being found over extended timeframes and therefore actively using the remnant.

Avifauna has also been separated into indigenous and exotic species based on the classification system of New Zealand Birds Online (2013) (Tab. 9). This allowed for analysis to be undertaken on the two groups finding that both indigenous and exotic bird species richness have seen an overall increase in Pūtaringamotu since 2004/2005 (Fig. 13). ANOVA indicates there was a significant difference present between the number of indigenous and exotic birds ($F = 36.57$, $df = 1$, $P = 0.03$) suggesting Pūtaringamotu is dominated by exotic species. This is likely a product of the history of anthropogenic influences as indigenous species dominance was quickly diminished in the region when predatory mammals were introduced and forests were removed isolating Pūtaringamotu from other indigenous forests (McGlone, 1989; Atkinson & Cameron, 1993).

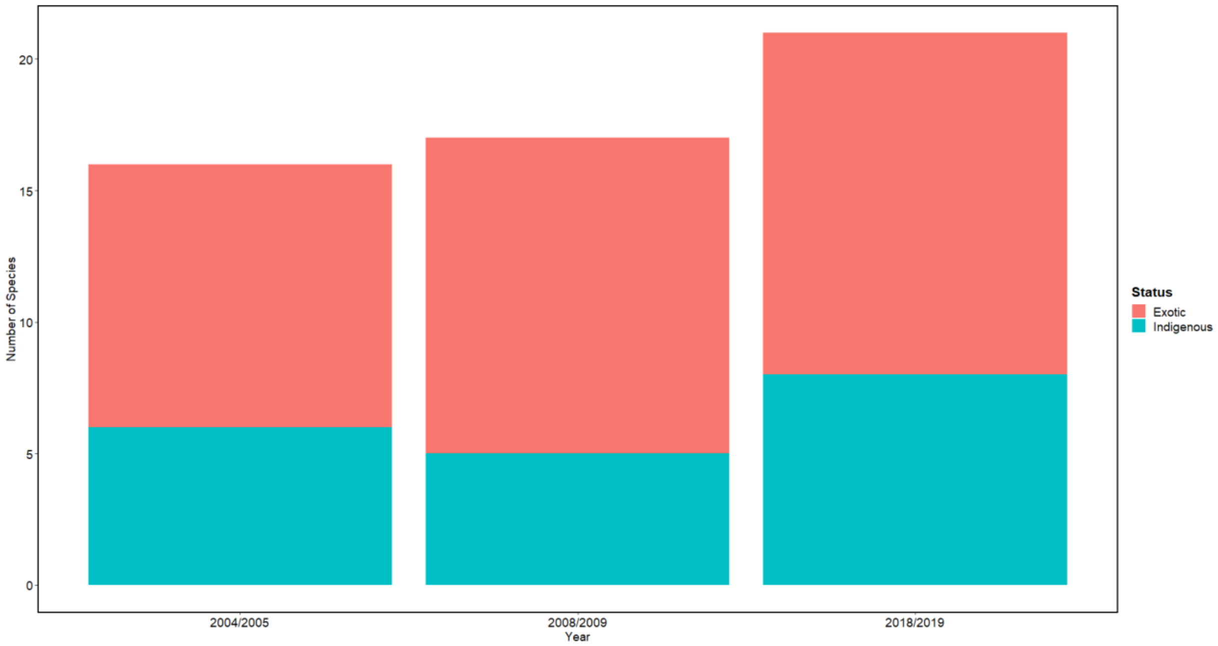

Figure 13: Stacked column chart of species richness present in Pūtaringamotu.

4.3.2 Shannon's Index

When conducting ANOVA for Shannon's index no significant difference in heterogeneity was detected between the different sampling periods (F = 0.72, df = 2, P = 0.58), despite this, it can be seen that there has been an increase in Shannon's index from 2004/2005 to 2018/2019 (Fig. 14). There was a significant difference between indigenous and exotic avifauna groups (F = 32.42, df = 1, P = 0.03). It can be seen that exotic avifauna contributed more to Shannon's index across all three sample periods (Fig. 14). The changes in Shannon's index indicate that thus far management has not resulted in more heterogenous avifauna.

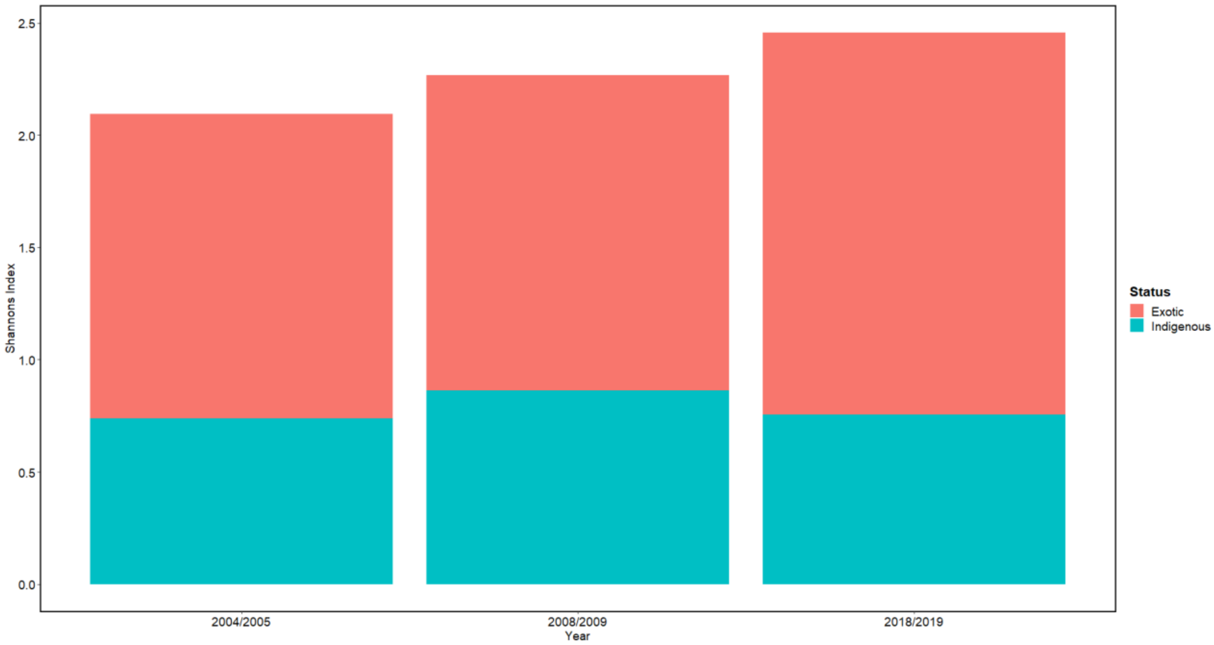

Figure 14: Stacked column chart of Shannon's index present in Pūtaringamotu.

4.3.3 Five-Minute Bird Count

4.3.3.1 Indigenous Species

Silvereye has remained the most prominent indigenous species present in Pūtaringamotu for the duration of this research with five-minute bird count totals of 409 in 2004/2005, 413 in 2008/2009, and 361 in 2018/2019 (Fig. 15). All other indigenous species have a much lower total bird count (Fig. 15, Fig. 16). All indigenous species experienced an increase in the number of individuals between 2004/2005 and 2008/2009 (Fig. 15, Fig. 16) which could be attributed to completion of the pest proof fence in 2004 (Innes, et al., 2012). From 2008/2009 to 2018/2019 three species (grey warbler, fantail, and silvereye) have decreased in number and two species (bellbird and kereru) have increased in number (Fig. 15, Fig. 16).

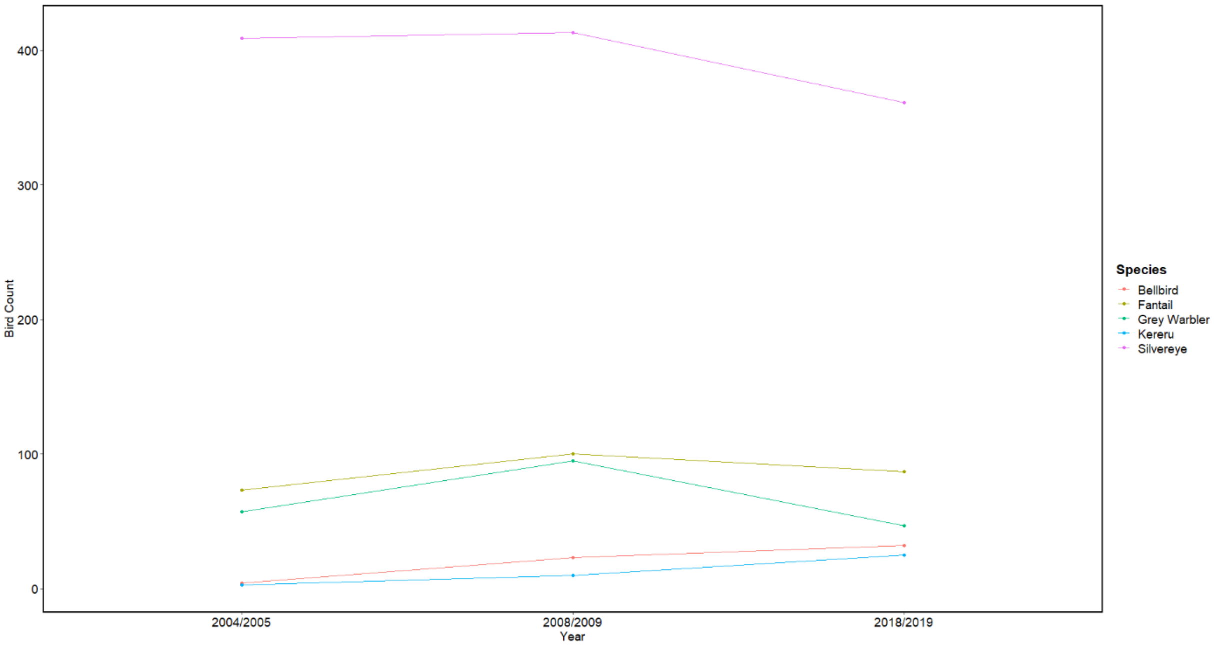

Figure 15: Line graph of indigenous species five-minute bird count (all species) 2004/2005 - 2018/2019.

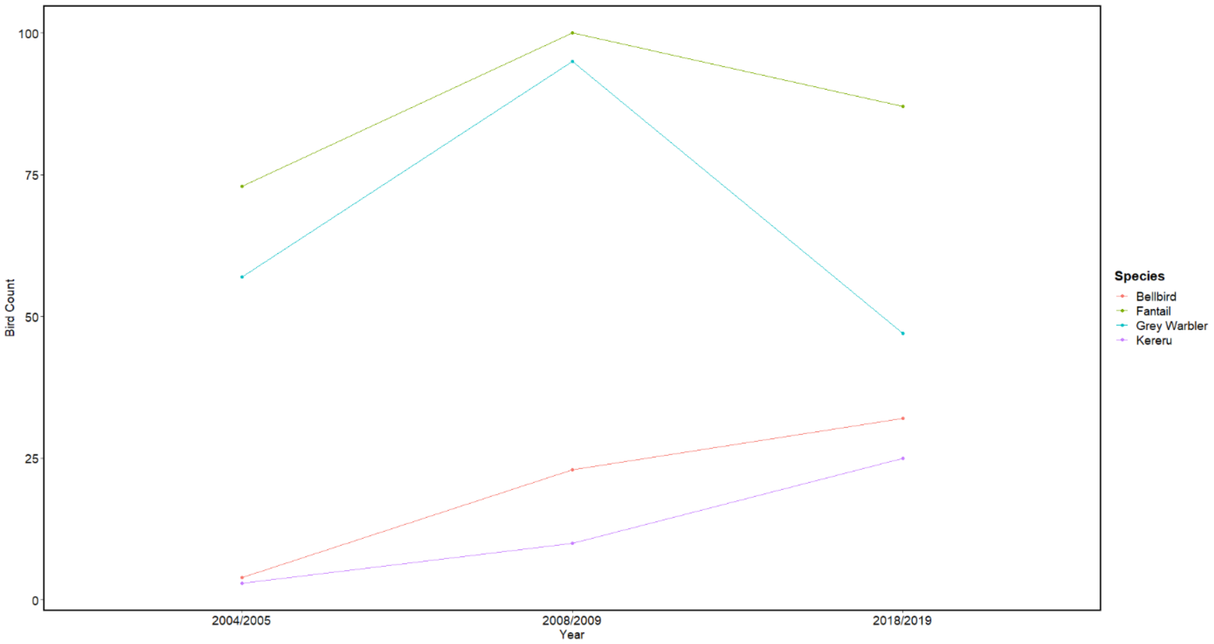

Figure 16: Line graph of indigenous species five-minute bird count (silvereye omitted) 2004/2005 - 2018/2019.

4.3.3.2 Exotic Species

The general trend displayed by exotic species in Pūtaringamotu is an upward trajectory in the number of individuals present between 2004/2005 and 2018/2019. Dunnock is the only species to experience a continual downward trend across all three sampling periods. A significant increase in the total number of individuals observed has occurred in Rock Pigeon which have increased from 0 individuals in 2004/2008 to 126 individuals in 2018/2019 (Fig. 17). This is thought to have occurred as Rock Pigeon began roosting in the remnant forest after the Canterbury earthquakes (Norton, 2020).

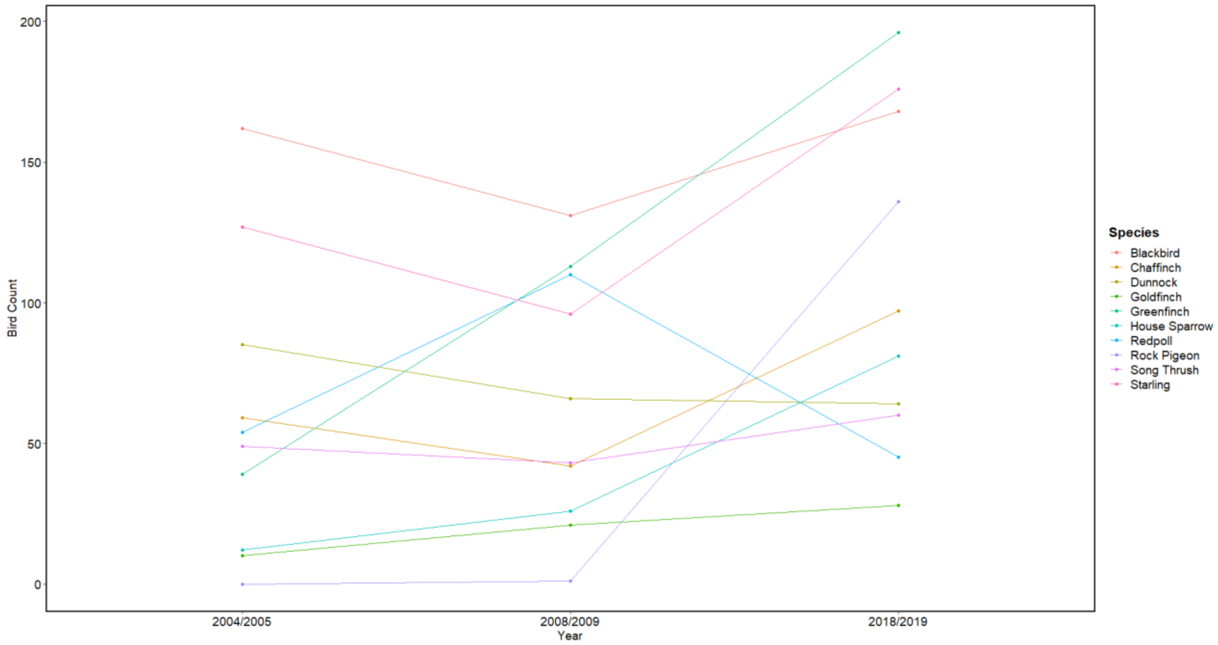

Figure 17: Line graph of exotic species five-minute bird count (all species) 2004/2005 - 2018/2019.

4.4 Summary

This research on avifauna in Pūtaringamotu assessed a 15-year period of avifaunal change from 2004/2005 to 2018/2019 to assess whether avifauna abundance, composition, and diversity had changed over the timeframe. Proxies have been used for this research with five-minute bird counts being used as a measure of abundance, indigenous and exotic birds being used as a measure of composition, and species richness and Shannon's index being used as a measure of diversity. Results from this research suggest that fundamental changes are yet to occur in the avifauna of Pūtaringamotu as is evidenced by the lack of significant differences between years. However, insignificant differences between sampling periods have been found for abundance and diversity suggesting changes are occurring but not at a significant level. Across all three sampling periods there is a significant difference apparent between indigenous and exotic avifauna suggesting exotic avifauna are more dominant within the remnant.

The hypothesis that overall species richness will significantly increase is rejected as no significant differences are found between sampling periods. However, a non-significant increase occurred between 2004/2005 and 2018/2019 indicating changes are occurring but not at a significant level. The hypothesis that Shannon's index will significantly increase is rejected as no significant difference was found between sampling periods. Although, the Shannon's index can be seen to increase over the three sampling periods. Finally, the hypothesis that there will be a significant difference apparent between indigenous and exotic specimen is accepted as significant differences are found between indigenous and exotic avifauna for species richness and Shannon's index.

Overall, the assessment of whether avifauna abundance, composition, and diversity has changed in the last 15 years in Pūtaringamotu found that significant differences between sampling periods were yet to occur. Although, indicators are present that suggest non-significant levels of change have occurred over the 15-year time period. It is recommended that data collection for avifauna continues to be undertaken on a regular basis in Pūtaringamotu as time will be a good indicator of whether current avifaunal trends will continue into the future. Hence, it is recommended that future research continues to be conducted on how avifauna are changing in Pūtaringamotu so to assess if fundamental changes are occurring as a result of the ecologically based management interventions over longer timeframes.

5 Synthesis

5.1 Introduction

Pūtaringamotu is a significant urban forest remnant located in the urban centre of Christchurch. It has been isolated in space from other sources of biological recruitment for over 100 years (Chinn, 2006) due to the land use changes which have occurred in the Canterbury region. The presence of the urban remnant in the centre of the Christchurch urban matrix is a testament to the forward-thinking actions of the Deans family who gifted the remnant to the people of Christchurch, with the remnant being formally gazetted as of 1914 (Molloy, 1995; Riccarton Bush Trust, 2015). Management of the remnant has varied over time with periods of benign neglect occurring which had adverse effects on biodiversity. Since the 1970s ecologically based management has been used in Pūtaringamotu to protect and enhance indigenous flora and fauna present in the remnant (Molloy, 1995; Riccarton Bush Trust, 2015).

This research has assessed the biodiversity outcomes for vegetation and avifauna resulting from management in the small 7.8 ha urban remnant known as Pūtaringamotu. The focus of the research has been to answer the overarching question; have fundamental biological changes occurred in Pūtaringamotu as a result of proactive ecological management established in this indigenous forest remnant? This has been achieved by meeting three main objectives:

1. Assessing whether vegetation abundance, composition, and diversity has changed in the last 20 years in Pūtaringamotu,
2. Assessing whether avifauna abundance, composition, and diversity has changed in the last 15 years in Pūtaringamotu, and,
3. Providing an understanding of how biodiversity in Pūtaringamotu has responded to changes in management in recent years and formulating management recommendations.

5.2 Recommendations for Management of Pūtaringamotu

This research has indicated that fundamental changes have not occurred in vegetation or avifauna. As such, management cannot be said to be improving biodiversity in the remnant. Despite this, it is likely that current management has had positive effects for maintaining the biodiversity values of the remnant as significant decreases in vegetation or avifauna have not occurred since the beginning of the sampling periods in 2000 for vegetation and 2004/2005 for avifauna. The relevant goal from the Riccarton Bush/Pūtaringamotu management plan for this research is; “protecting and enhancing flora and fauna of the indigenous forest including mahinga kai and taonga species” (Riccarton Bush Trust, 2015). This research has indicated that the protection of flora and fauna in the indigenous remnant is occurring as is evidenced by the lack of significant decreases for vegetation and avifauna. However, enhancement of indigenous flora and fauna in the remnant is not occurring as is evidenced by the lack of significant improvements in vegetation and avifauna. As such, several recommendations have been made to the Riccarton Bush Board of Trustees that will further enhance the management of Pūtaringamotu.

5.2.1 Recommended Improvements

Three recommendations for the Riccarton Bush Board of Trustees have been formulated to improve management within Pūtaringamotu. These management recommendations will address issues that have been found in this research including the lack of indigenous dispersal from outside the remnant for vegetation and avifauna, the increase in weed presence found on the forest edges (Fig. 5), and the increase in Rock Pigeon numbers in the 2018/2019 five-minute bird counts (Fig. 17). Management recommendations are as follows:

1. Artificially introduce vegetation and avifauna from the Canterbury region into Pūtaringamotu.

The isolated nature of the remnant means that the number of indigenous vegetation species remains static and incursion of appropriate indigenous species into the remnant is unlikely to occur naturally (Molloy, 1995). Therefore, into the future measures could be put into place to reintroduce appropriate vegetation and avifauna into the remnant forest. This should be done using vegetation and avifauna local to the Canterbury region to ensure genetic material is conserved (Norton, Butt, & Bergin, 2018). Artificially introducing species will lower the risk of extinction in the long term by increasing the genetic pool available within the small urban remnant allowing a viable population of vegetation and avifauna to be sustained (Aguilar, Ashworth, Galetto, & Aizen, 2006; Miskelly, 2018).

2. Increase weed control on remnant edges.

The urban environment surrounding Pūtaringamotu increases the rate at which weed incursions occur in the forest (Molloy, 1995). Weeds characteristic of the surrounding urban environment were found mainly along the remnant edges of Pūtaringamotu in 2020. This is because forest edges in Pūtaringamotu are closest to the surrounding urban matrix. Weeds are also likely to occur here as the cleared and replanted fringe has not had enough time to establish significant cover to shade out weed species which are entering the forest (Rowley, Edwards, & Kelly, 1993; McAlpine, Lamoureaux, & Westbrooke, 2015). While weed control is already part of the management plan, it is recommended that increased checks take place along remnant edges into the future.

3. Regularly cull Rock Pigeons present in Pūtaringamotu.

Rock Pigeons have become a significant pest species in Pūtaringamotu, having only become abundant in the forest in the 2018/2019 five-minute bird counts (Fig. 17). They have had significant negative effects on the remnant by taking roosting space from indigenous avifauna and have the potential to spread disease to other birds in the forest which will negatively impact on biodiversity (Norton, 2018; Norton, 2020). Therefore, it is recommended that culling takes place on a more regular basis to ensure Rock Pigeon abundance is kept under control within the remnant.

5.3 Concluding Remarks

5.3.1 Objectives Achieved

The overall objective of this thesis was to answer the question; have fundamental biological changes occurred in Pūtaringamotu as a result of proactive management established in this indigenous forest remnant? This question was answered by assessing the response of vegetation and avifauna to management over the past 20 years and 15 years respectively. The overall findings of this thesis conclude that neither vegetation nor avifauna have experienced fundamental changes over the timeframe of this research. This is not to say that fundamental changes will not occur into the future as early indications from this research show changes are beginning to become apparent. Therefore, it is of utmost importance that the biodiversity of Pūtaringamotu continues to be monitored so to establish when and where fundamental changes are occurring in vegetative and avifaunal biodiversity. While this research concluded that fundamental changes had not occurred in Pūtaringamotu, it has still filled a gap in knowledge on how biodiversity groups respond to management in established small urban remnants rather than often-studied larger urban remnants (Innes, et al., 2019; Wallace & Clarkson, 2019). It has also provided an update on the biodiversity found in Pūtaringamotu which was last extensively detailed in the 1970s and 1980s in the book Riccarton Bush: Pūtaringamotu (Molloy, 1995).

5.3.2 Limitations and Future Objectives

This research was limited by the small period of time in which consistent sampling of vegetation and avifauna had taken place. This occurred as prior to 2000 sampling of vegetation and avifauna in Pūtaringamotu used study designs which were inconsistent between sampling periods, making it difficult to directly compare results (Molloy, 1995). This made it difficult to establish whether changes in biodiversity had occurred in the intervening period between the 1970s when proactive ecological management was first instated and 2000 when consistent sampling first began. As such, this research could realistically only cover the timeframes of consistent sampling, allowing for a 20-year sampling period from 2000 to 2020 for vegetation, and a 15-year sampling period from 2004/2005 to 2018/2019 for avifauna. Therefore, it is recommended that consistent sampling methods continue to be used to monitor vegetation and avifauna in Pūtaringamotu to allow this research to be replicated in the future. This will allow for the biodiversity responses of vegetation and avifauna to be assessed over a longer timeframe to give a clear indication of whether management is sustaining or improving biodiversity in Pūtaringamotu.

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